INSTITUTE NOTES.

JULY, 1940.

TELEGRAPHIC ADDRESS.

Telegrams and cables for the Institute should be addressed: "INSTPETECH BIRMINGHAM."

CANDIDATES FOR ADMISSION.

The following have applied for admission to the Institute or transfer to another grade of membership, and in accordance with the By-laws the proposals will not be considered until the lapse of at least one month subsequent to the issue of this *Journal*, during which any Fellow, Member, or Associate Member may communicate by letter to the Secretary, for the confidential information of the Council, any particulars he may possess respecting the qualifications or suitability of any candidate.

The object of this information is to assist the Council in grading candidates according to the class of membership.

The names of the candidate's proposer and seconder are given in parentheses.

KUHN, Wayne Edward, Ph.D., Chemical Engineer. (*The Texas Company*) 135 East 42nd Street, New York. (*K. G. Mackenzie; L. de Florez.*)

MILLS, Leonard, Chemist, 55, County Road, Ormskirk, Lancs. (*Vigzol Oil Refining Co., Ltd.*) (*P. Bilton; S. Elliman.*)

MOON, Alec, Engineer, c/o Messrs. Shell-Mex & B.P., Ltd., Shell-Mex House, London, W.C.2. (*R. G. Strickland; H. E. Priston.*)

Steels specially suitable for the Oil Industry

ERA TRADE MARK **MANGANESE STEEL** for Sprocket Wheels, Pulleys, etc.

ERA C.R. **NON-CORRODING STEEL** for Thermowells

ERA H.R. **HEAT-RESISTING STEELS** for Tube Supports, Heat Exchangers, etc.

Damper Plates and Frames of Hadfields "Era H.R.3" Steel

HADFIELDS LTD

EAST HECLA AND HECLA WORKS

SHEFFIELD . . . . . ENGLAND

No. 2334

Kindly mention this Journal when communicating with Advertisers.

A NEW A.S.T.M. PUBLICATION

EVALUATION OF PETROLEUM PRODUCTS

A Résumé of Present Information

The primary purpose of this new publication of the American Society for Testing Materials is to stress important problems on which research and testing work should be developed to result in standardized testing procedure and specification requirements.
Comprising six authoritative papers by outstanding technologists, the book covers the subjects of Gasoline, Diesel Fuels, Fuel Oils, Lubricating Oils, Lubricating Greases, and Fuel and Lubricating Oils for Spark-Ignition Aircraft Engines.

Price **5s.** *(post free)*

Obtainable from

THE INSTITUTE OF PETROLEUM

c/o The University, Edgbaston, Birmingham, 15

LIST OF ADVERTISERS.

	PAGE
Aktiebolaget Elektrisk Malmletning	—
Audley Engineering Co., Ltd.	—
C. R. Averill, Ltd.	Inside back cover
Babcock & Wilcox, Ltd.	xii
Baker Oil Tools Inc.	viii
Cardwell Mfg. Co.	xi
W. Christie & Grey, Ltd.	iii
A. F. Craig & Co., Ltd.	vi
Charles Dabell & Co.	—
Foster Wheeler, Ltd.	—
W. J. Fraser & Co., Ltd.	iv
Geophysical Prospecting Co., Ltd.	—
Hadfields, Ltd.	i
Hayward-Tyler & Co., Ltd.	—
Institute of Petroleum	ii
International Paint & Compositions Co., Ltd.	iii
Lane-Wells Co.	—
Lummus Co.	ix
National Supply Corporation	v
Oil and Petroleum Year Book	—
Oil Well Supply Co.	—
Security Engineering Co., Inc.	—
Société de Prospection Électrique	—
John G. Stein & Co., Ltd.	x
Stewarts and Lloyds, Ltd.	Back cover
Svenska Diamantbergborrnings Aktiebolaget...	—
Tintometer, Ltd.	—
Wheeler Foundry and Engineering Co. Ltd.	vii

Kindly mention this Journal when communicating with Advertisers.

T

By A

held
the
nom
in th
for s
is ap
pres
a te
the
prop
on t
whi
cher
G
indi
seco
diff
dep
hill,
coal
" ke
" w
at
Of
Ren
new
bee
the

Vol. 26. No. 201. July 1940.

THE CLASSIFICATION OF OIL SHALES AND CANNEL COALS.*

By A. L. Down, Ph.D., A.R.C.S., D.I.C., and G. W. Himus, Ph.D., M.I.Chem.E., A.R.C.S.

Synopsis

Attention is directed to the confusion that exists in the nomenclature and classification of naturally occurring oil-yielding materials. A system of nomenclature based on the principal plant and mineral constituents and a classification showing the inter-relationships and gradation of properties of these substances is put forward.

At the Plenary Session of the Conference on Oil Shale and Cannel Coal, held at Glasgow in 1938, a resolution [1] was passed "That the Council of the Institute of Petroleum be invited to take steps to secure a standard nomenclature of the various oil-producing materials discussed or described in the various papers submitted to the Conference." The urgent need for such a standardized nomenclature, and also for a rational classification, is apparent from even a brief study of the literature. The object of the present paper is to suggest a rational system of nomenclature, coupled with a tentative classification which shall show the inter-relationships between the various classes of oil-yielding materials. While it is realized that the proposed classification is not final, in the opinion of the authors it is based on the most satisfactory data available, and may serve as a foundation on which further classifications can be developed as our knowledge of the chemistry of these materials increases.

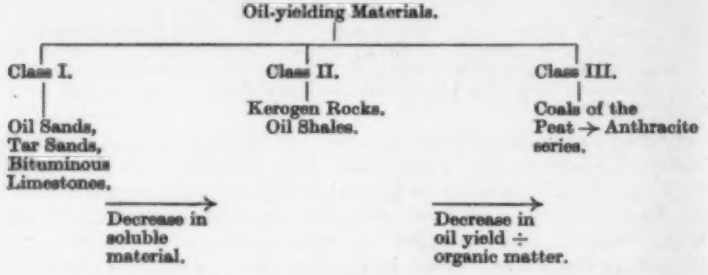
Great confusion has arisen from two main causes—firstly, owing to the indiscriminate use of the terms "oil shale" and "cannel coal," and secondly, due to the great variety of names which have been applied by different investigators to one particular type of substance. Thus, different deposits containing large numbers of algæ † (*i.e.*, similar to that at Torbanehill, Scotland) have been variously referred to as "torbanite," "boghead coal," "algal coal," "albertite," "stellarite," "bathvillite," "bituminite," "kerosine shale," "brown cannel coal," "petroleum-oil-cannel-coal," "wollongite," etc., the last four being special names which have been applied at various times to the New South Wales "boghead" or "torbanite." Of these names, only "algal coal," which was suggested by Bertrand and Renault,[2] gives any indication as to the nature of the material. In any new system of nomenclature it is essential, first, to avoid names which have been widely misused hitherto, and secondly, to employ terms descriptive of the main constituents of the materials.

* Paper received 11th July, 1939.

† Although there has been much controversy as to the precise nature of the yellow bodies originally called "algæ" by Edgeworth David in 1889, the researches of K. B. Blackburn and B. N. Temperly [5] have, in the opinion of the authors, satisfactorily settled the question in favour of the algal theory.

Primary Classification.

Examination of the naturally-occurring materials from which oil can be obtained by heat treatment shows that they fall into three main classes: Class I, substances from which the greater part of the organic matter can be extracted by the normal solvents for petroleum; Class II, substances which yield 50 per cent. or more of their organic matter as an oil on heat treatment, but from which only a small proportion of the organic matter can be extracted by solvents; and Class III, material formed almost entirely from highly altered plant remains which yield only about 15 per cent. of the organic matter as oil.


Oil-yielding Materials.
Class I.
Oil Sands, Tar Sands, Bituminous Limestones.
Class II.
Kerogen Rocks. Oil Shales.
Class III.
Coals of the Peat → Anthracite series.
Decrease in soluble material.
Decrease in oil yield ÷ organic matter.

These main groups are by no means sharply defined, and intermediate types are frequently met. Thus, R. H. McKee, working on a sample from Ione, California, obtained 10·98 per cent. extract with acetone and 10·16 per cent. extract with chloroform, both of which are equivalent to approximately 50 per cent. of the oil yield on distillation. The gap between Classes II and III is bridged by the variety of materials commonly referred to as cannel coals.

The scope of the present paper is confined to Classes II and III, the detailed work required for its extension to Class I not yet having been carried out.

Since the names "oil shale" and "cannel coal" have been frequently misused, and since the term "oil shale" is misleading, whilst "cannel" gives no indication of the nature of the material to which it is applied, it is advantageous to avoid using either. True oil shales contain no oil as such, the oil is only formed by the destructive distillation of the organic matter, to which Crum Brown applied the name "kerogen," or "oil-former," thus the materials in Class II may be given the general group-name "kerogen rocks." An important distinction between kerogen rocks and coals is the high proportion of mineral matter in the former. For the materials bridging the gap between Classes II and III (formerly known as "cannel coals") the general name "kerogen coals" is suggested since the organic matter yields a relatively high proportion of oil and they are frequently associated with coals.

Whereas the banded constituents of bituminous coals may be sub-divided solely on a basis of the organic matter, the relatively small percentages of associated minerals being unimportant, in dealing with the kerogen rocks the chief mineral constituents must be taken into account. Only the general

differences can be detected from the examination of hand specimens and, in the present state of our knowledge, the only satisfactory method of classification of kerogen rocks is one based on their principal organic constituents, as revealed by microscopic examination, and the nature of the associated mineral matter as determined by chemical analysis.

General Considerations on Kerogen Rocks and Kerogen Coals.

It is generally accepted that in the great range of organic deposits of sedimentary origin, the source-material was vegetable matter, and animal remains played little or no part. Strong support for this view is found in the work of H. R. J. Conacher,[4] who made comparative tests on (*inter alia*) normal Levenseat oil shale and on a sample from a band crowded with shells of lingula; he found that although the shells caused considerable increase in the percentage of ash, the yields of oil, when calculated on the dry, ash-free basis, were identical within the limits of experimental error. Moreover, there was no appreciable difference between the specific gravities and setting points of the oils from the normal shale and the lingula band.

The existence of such a great range of related materials can be attributed to two primary causes: (i) differences in the original plant materials, and (ii) differences in the conditions of deposition and the subsequent history of the deposits. The number of intermediate materials exhibiting a gradation of properties arises from the possibilities of mixtures of the source materials in various proportions and the limited number of proximate plant constituents. There is no evidence to suggest that there has been any essential alteration in the composition or constitution of these proximate plant constituents through the ages.

Kerogen Rocks.

The kerogen rocks are sedimentary deposits, containing organic matter, of which approximately 50 per cent. is yielded as an oil when the rock is heated to about 500° C.; they are very widely distributed, occur in continuous seams, covering considerable areas, and may differ widely in age. They are not usually intimately associated with coal seams. The kerogen content is very variable, and may range from 50 per cent. upwards to practically zero.

Examples of kerogen rocks of very different geological ages are: Esthonian (Lower and Middle Ordovician), Swedish (Silurian), American (Tertiary), Australian and Brazilian (Recent).

The great majority of kerogen rocks, when examined in thin sections under the microscope, show unresolvable masses of macerated plant debris containing a few spores and/or algæ. This organic matter can only be called "kerogen," hence the rocks may be logically designated "kerogen shales" or "kerogen limestones," according to the preponderating mineral constituent. Samples are found in which the organic matter consists in great measure of spores or algæ and where these recognizable constituents preponderate, it is suggested that the word "kerogen" should be replaced by the name of the recognizable constituent which predominates.

Typical photomicrographs of representative kerogen rocks are shown in Figs. 1 to 4.

Kerogen Coals.

Kerogen coals are carbonaceous materials in which the organic matter is preponderant; they occur in lenticular patches, usually over a very limited area, and often associated with bituminous coals, with which they may form a compound seam, or into which they may grade either laterally or vertically. The majority of kerogen coals which have been described are of Carboniferous or Permo-Carboniferous age.

Under the microscope, thin sections show that the kerogen coals contain much macerated plant debris with considerable numbers of either algæ or spores, or both spores and algæ.

A number of these materials have been illustrated and described by W. J. Skilling.[6] Among these are the following: Lower Dysart, Fife, yielding 23·1 per cent. ash, is an algal coal; the Humph (16·2 per cent. ash) is a spore coal, while the 18-inch seam, New Cumnock, Ayrshire (16·2 per cent. ash), which contains both algæ and spores, is an intermediate type, or an algal-spore coal. Other examples of algal-spore coals are the Mercer, Pennsylvania, illustrated by R. Thiessen,[7] and the Kentucky, illustrated by E. C. Jeffrey.[8]

Deposits are known the organic constituents of which are similar to those of an algal coal, but which contain large proportions (50 per cent. or more) of mineral matter, predominantly clay, and owing to this high mineral content, these materials must be classified as algal shales, forming a link between the two main groups of kerogen rocks and kerogen coals. The Ermelo algal shale consists of masses of algæ embedded in a groundmass of unresolvable plant debris, as shown in the photomicrograph, Fig. 5. The proximate composition of this material shows it to contain kerogen and mineral matter in approximately equal proportions; the mineral matter consists of clay plus excess silica, with only 0·5 per cent. of carbonates. The Parrot Rough (Skilling, *loc. cit.*) is a similar material.

There is a related group in which the organic matter consists almost entirely of algæ, and in which the mineral matter may vary from as little as 5 per cent. to as much as 30 per cent. These materials are a special intermediate type between algal coals and algal shales, for which the only logical name is "algal rock," since algæ are the only important constituent. That so few algal rocks are known is due to the rarity of the occasions when the requisite enormous numbers of algæ, free from appreciable quantities of extraneous vegetable materials, became accumulated and preserved.

The spore coals grade insensibly into the durain of bituminous coals.

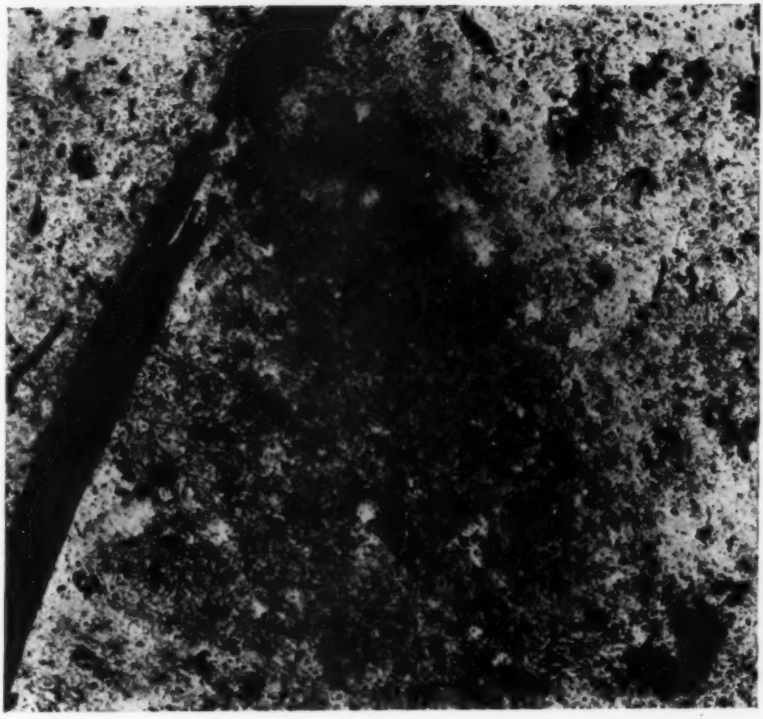
The foregoing conclusions as to the properties, differences, and inter-relationships of these groups of materials have been set out in tabular form.

Conclusions.

1. Naturally occurring oil-yielding materials can be primarily divided according to the solubility of the organic constituents in the usual solvents for petroleum.

2. The insoluble materials can be divided into kerogen rocks, kerogen coals, and members of the peat-to-anthracite series.

3. The various groups can be sub-divided according to the chief plant



Horizontal.

Vertical.

FIG. 1.

KIMERIDGE KEROGEN SHALE, NORFOLK, SHOWING LAMINATED OR SHALEY STRUCTURE AND MACERATED PLANT DEBRIS. × 150.

[*To face p.* 332.

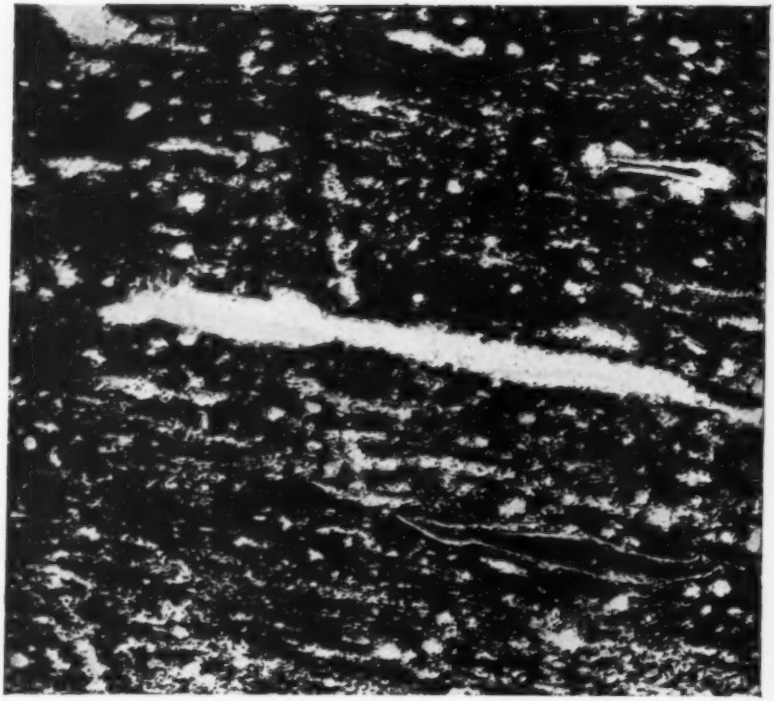
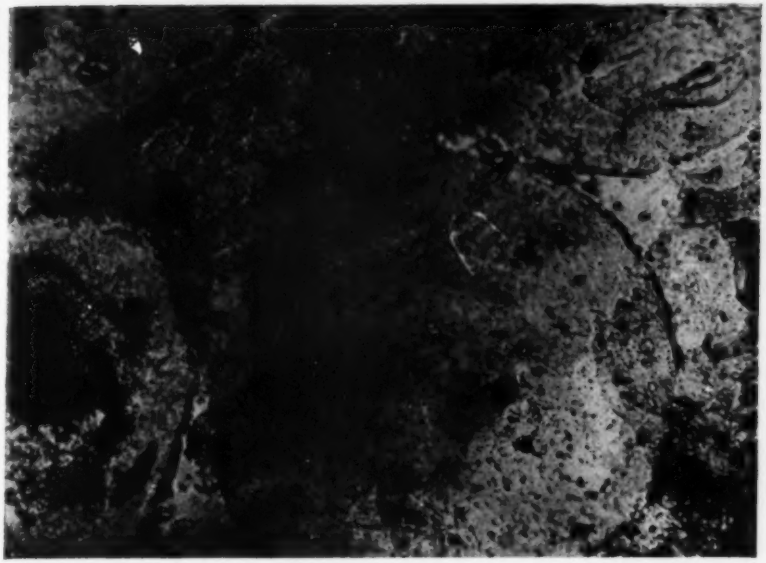
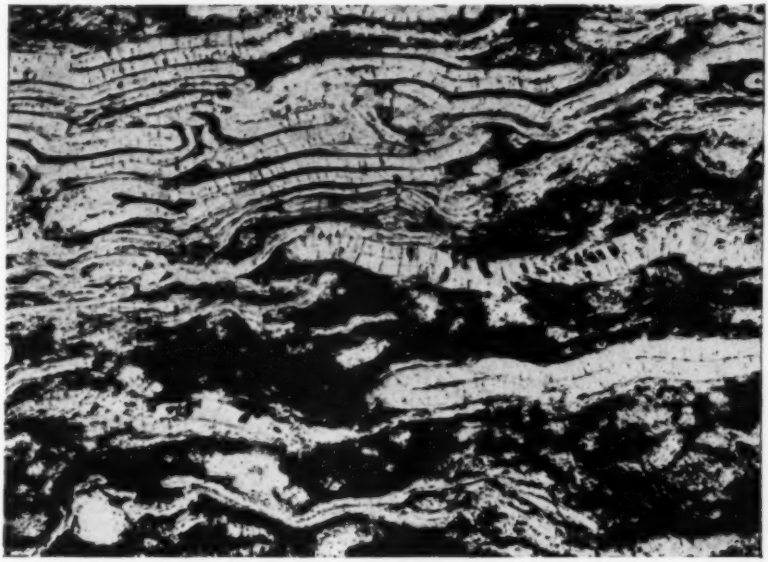


FIG. 2.

BROXBURN MAIN KEROGEN SHALE, SCOTLAND, SHOWING LAMINATED OR SHALEY STRUCTURE AND MACERATED PLANT DEBRIS. VERTICAL SECTION. × 150.



Horizontal.



Vertical.

FIG. 3.

TASMANIAN SPORE SHALE SHOWING THE GREAT PREPONDERANCE OF CRUSHED SPORE CASES AND THE ABSENCE OF OTHER PLANT REMAINS. × 150.

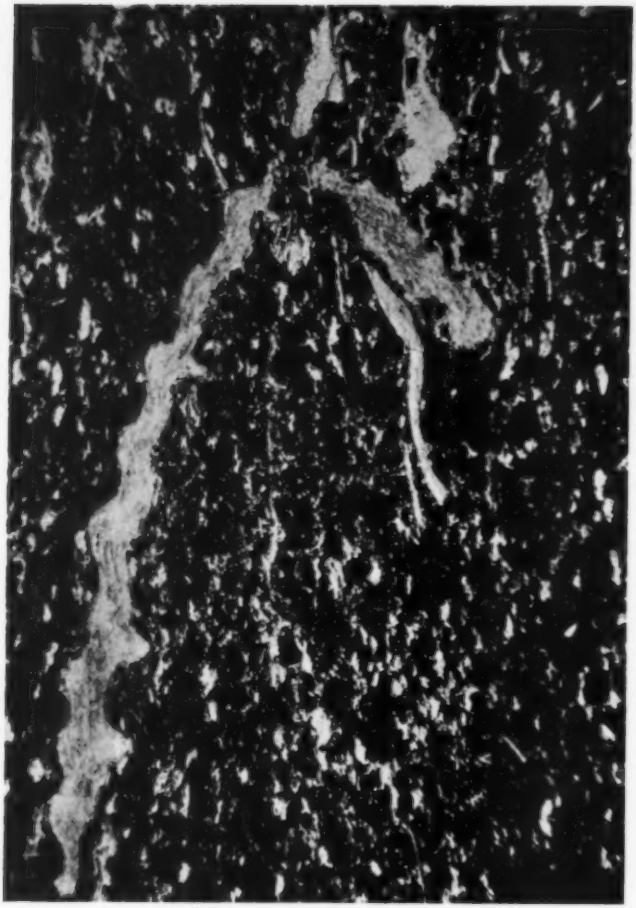
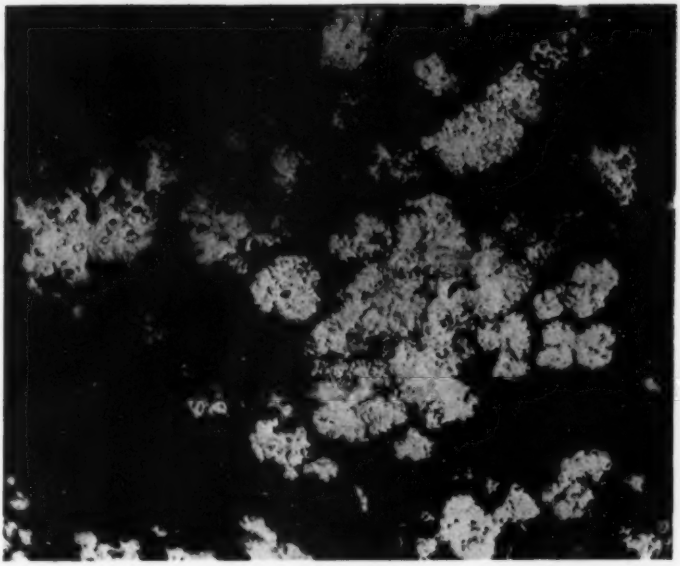
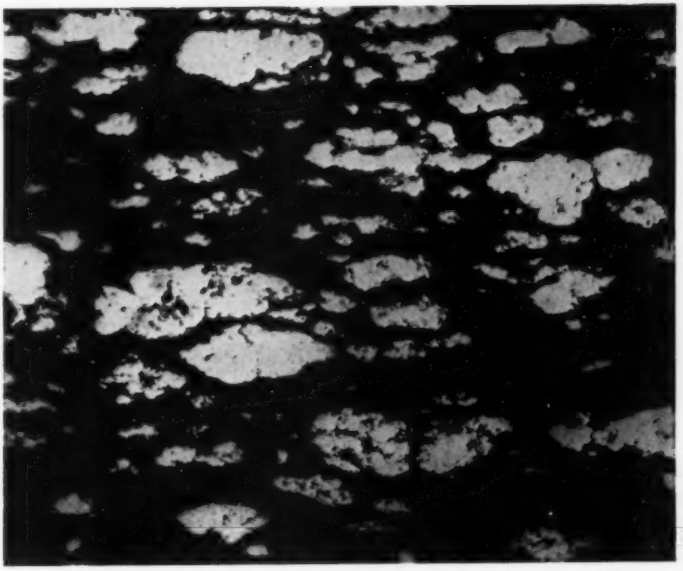


FIG. 4.

ESTHONIAN ALGAL LIMESTONE, WITH GREAT ACCUMULATION OF ALGAL COLONIES TOGETHER WITH PIECES OF SHELLS. HORIZONTAL SECTION. × 150.



Horizontal.



Vertical.

FIG. 5.

ERMELO ALGAL SHALE, SOUTH AFRICA, SHOWING ALGAL COLONIES IN A DARK UNRESOLVED MATRIX. × 150.

constituents as seen in thin sections under the microscope, and the nature of the mineral matter, where important.

4. A rational nomenclature is based on the nature of the plant remains plus the nature of the mineral matter (where important), prefixed by an adjective explanatory of the locality from which the material was obtained.

ACKNOWLEDGMENTS.

We desire to express our thanks to Professor A. C. G. Egerton, F.R.S., for his continued interest in the researches on oil-yielding materials, and to Dr. R. Crookall of the Geological Survey for the helpful suggestions he has made, also to Dr. J. M. Connor for his assistance in taking the photo-micrographs.

Department of Chemical Technology,
Imperial College, S.W.7.
5th July, 1939.

References.

[1] "Oil Shale and Cannel Coal," 1938, p. xix.
[2] C. E. Bertrand, *Bull. Soc. Industr. Min.*, 1892, ser. 3, **6**, 453–506, and later papers.
[3] R. H. McKee, "Shale Oil." A.C.S. Monograph, 1925.
[4] H. R. J. Conacher, *Trans. Geol. Soc. Glasgow*, 1917, **16**, 170.
[5] K. B. Blackburn and B. N. Temperly, *Trans. Roy. Soc. Edin.*, 1936, **58**, 841–868.
[6] W. J. Skilling, "Oil Shale and Cannel Coal," 1938, p. 32.
[7] R. Thiessen, "Origin of the Boghead Coals." U.S. Geol. Surv. Professional Paper 132, I, 1925.
[8] E. C. Jeffrey. "Coal and Civilization," 1923, p. 45.
[9] A. E. Flynn, National Research Council of Canada, Report No. 18, 1926.
[10] A. Raistrick and C. E. Marshall, "The Nature and Origin of Coal Seams," 1939; W. A. Bone and G. W. Himus, "Coal, Its Constitution and Uses," 1936.
[11] Tasmanian Geological Survey, Mineral Resources Bulletin, 1933, **2**, No. 8.
[12] J. M. Petrie, *J. Soc. chem. Ind.*, 1905, **24**, 996–1002.
[13] H. P. W. Giffard, "Oil Shale and Cannel Coal," 1938, p. 78.

THE CLASSIFICATION OF KEROGEN ROCKS

SHOWING THEIR INTER-RELATIONSHIPS AND

KEROGEN ROCKS.

General Definitions and Field Relations. Sedimentary rocks containing organic matter which, on distillation, yields an oil, equivalent to approximately 50% of the organic content. Occur in continuous seams, covering considerable areas. Generally not associated with coal.

Principal Organic Constituents.	Spores.	Algæ.	Macerated plant debris.		Algæ and macerated plant debris.
Principal Mineral Constituents.	Clay.	Limestone.	Limestone.	Clay.	Clay.
Structure.	Laminated.	Massive.	Massive.	Laminated.	Microclastic.
Proposed Nomenclature.	**SPORE SHALE.**	**ALGAL LIMESTONE.**	**KEROGEN LIMESTONE**	**KEROGEN SHALE.**	**ALGAL SHALE.**
Examples, using Present Name.	Tasmanite.	Kukersite.	Kohat Oil Shale.	Scottish Oil Shales.	Ermelo Torbanite, Stellarite.[9]
Proposed Names.	TASMANIAN SPORE SHALE.	ESTHONIAN ALGAL LIMESTONE.	KOHAT KEROGEN SHALE (Calcareous).	SCOTTISH KEROGEN SHALE.	ERMELO ALGAL SHALE, PICTOU ALGAL SHALE.
Microstructure.	Large numbers of flattened spore cases, embedded in fine mudstone.	Masses of algæ with shells and silt.	Varying amounts of plant debris, not highly compact, with a few spores, algæ and crystals of mineral matter (calcite, dolomite, pyrite, etc.) in a brownish matrix lacking visible structure. Fish remains.		Decrease in algal content. ← Increase in drifted constituents, *i.e.* plant debris and mineral matter.
Conditions of Deposition.	Organic matter mainly drifted.	Organic matter accumulated *in situ*.	Organic matter accumulated partly *in situ*, partly drifted.		Organic matter accumulated mainly *in situ*.

Proximate Composition.	*Tasmanian Spore Shale.*[11]	Esthonian Algal Limestone.	Kohat Kerogen Shale.	Broxburn Main Kerogen Shale.	Ermelo Algal Shale.
Kerogen	*26*	52	11·85	26·0	53·65
Clay	27	9·25	41·95	45·2	31·3
Excess Silica	*33*	5·75	8·0	8·4	11·3
$CaCO_3$	*Low*	26·95	20·3	2·1	{ 0·5
$MgCO_3$	—	—	7·35	1·95	
$FeCO_3$	—	—	3·5	9·0	

Approximate ratio $\frac{\text{oil yield}}{\text{organic residue}}$ — Ermelo Algal Shale, 0·6

Oils obtained on carbonisation at 500° to 600° C., often contain paraffin wax (up to 10%), generally contain less than 10% of material soluble in aqueous caustic soda and have a calorific value of *over* 17,000 B.Th.U.'s per pound.

Note (1). Proximate compositions in italics are calculated from data given in references 11 and 12. The remainder from analyses by the authors.

Note (2). References 6 to 10 are to photomicrographs of the examples cited.

ROCKS AND KEROGEN COALS.

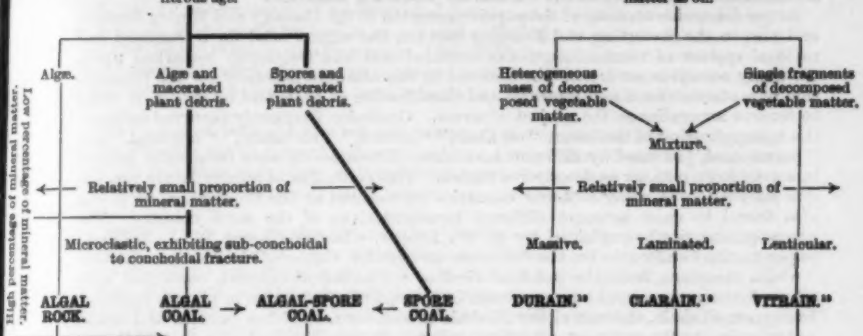
THEIR GRADATION INTO BITUMINOUS COALS.

KEROGEN COALS.

Carbonaceous materials, in which the organic matter preponderates, occurring in lenticular patches, usually over very limited areas. Often associated with bituminous coals, with which they may form a compound seam, or into which they may grade either laterally or vertically. The majority are of Carboniferous or Permo-Carboniferous age.

COALS.

Accumulations of fossilised plant debris, forming seams covering considerable areas, associated with relatively small amounts of mineral matter. On distillation, yield about 10% of the organic matter as oil.


Low percentage of mineral matter.
Algæ.
Algæ and macerated plant debris.
Spores and macerated plant debris.
Heterogeneous mass of decomposed vegetable matter.
Single fragments of decomposed vegetable matter.
Mixture.
Relatively small proportion of mineral matter.
Relatively small proportion of mineral matter.
Microclastic, exhibiting sub-conchoidal to conchoidal fracture.
Massive.
Laminated.
Lenticular.
ALGAL ROCK.
ALGAL COAL.
ALGAL-SPORE COAL.
SPORE COAL.
DURAIN.[10]
CLARAIN.[10]
VITRAIN.[10]
Joadja Creek Shale.[7] Torbanehill Mineral.[8]
Lower Dysart Cannel, Fifeshire.[9]
Mercer Cannel Pennsylvania.[7] Kentucky Bogheed.[9]
Humph Cannel, Lanarkshire.[9]
Banded Constituents of British Bituminous Coal.
JOADJA CREEK ALGAL ROCK. TORBANEHILL ALGAL ROCK.
LOWER DYSART ALGAL COAL.
MERCER ALGAL-SPORE COAL. KENTUCKY ALGAL-SPORE COAL.
HUMPH SPORE COAL.
A mass of pale yellow algal colonies, so dense as to leave very little opaque matrix.
Increase in algal content.
A mixture of algæ, spore cases and bits of cuticle, embedded in a groundmass of highly decomposed plant debris. Often a greater proportion of matrix than recognisable constituents.
Decrease in algal content.
A concentrated mass of micro- and macro-spore cases, cuticles and fragments of spores and cuticles, and resin lumps, embedded in an unresolvable mass of macerated plant debris.
Thin bands and shreds of vitrain and durain.
Very nearly homogeneous black mass. Usually each shred is a single piece of plant debris in an advance state of decay and highly compressed.
Increase in macerated plant debris, but *not* in mineral matter.
Fish remains.

Organic matter accumulated *in situ*.

Organic matter accumulated partly *in situ* and partly drifted.

Increase in proportion of drifted material.

Vegetable debris generally accumulated *in situ*. Sometimes drifted.

Joadja Creek Algal Rock.[13]
93
3·2
3·5
{ *Traces.* }

On account of the low proportion of mineral matter, a knowledge of its proximate composition is of little significance.

Joadja Creek Algal Rock. 10

Lower Dysart Algal Coal. 1·4

Humph Spore Coal. 0·6

The ratios for a number of British bituminous coals were all of the order of 0·2.

Torbanehill Algal Rock. 5·7

Oils obtained by carbonisation at 500° to 600° C. do not contain paraffin wax, generally contain upwards of 30% of material soluble in aqueous caustic soda and have calorific values of approximately 16,000 B.Th.U.'s per pound.

DISCUSSION.

CAPT. W. H. CADMAN (*Anglo-Iranian Oil Co.*): At the final Plenary Meeting of the successful first International Conference on Oil Shale and Cannel Coal, organized by this Institute, and which was held in Scotland in June 1938, one of the Sectional Resolutions submitted and carried unanimously called for steps to be taken to secure a standard nomenclature of the various oil-producing materials.

In the discussion on some of the papers presented to the Geology and Mining Section, and also to the Retorting and Refining Section, the urgent need for a standard and rational system of nomenclature was revealed and was frequently remarked upon. On many occasions attention was directed to the absolute necessity for the formulation of a standardized and international classification of coals and oil shales, in order to remove anomalies on the subject of terms. Confusion frequently occurred owing to the misapplication of the terms "oil shale," "cannel," "torbanite," "boghead," and "parrot coal," as used by different members. These words were frequently applied in a very loose manner as descriptive names. This confusion in nomenclature was not due merely to the many different countries represented at the Conference, as it was also found to exist amongst different representatives of the same country. The anomaly was partly explained by G. W. Lepper, when discussing W. J. Skilling's paper to the Conference on the "Nature of Scottish Cannels," in his remarks that "while, therefore, from the point of view of the technical chemist, concerned with oil production, there might be an almost imperceptible graduation in his raw material, from poor oil shale, through richer oil shale to lean cannels, richer cannels, and finally to torbanite, to the geologist, oil shales and cannels were lithologically distinct."

In the section on "Oil Shale Occurrence and Geology" in volume 4 of the "Science of Petroleum," it is also partly explained by H. R. J. Conacher, where he says that while the term "oil shale" is precisely applicable to the rocks or the material which is worked on a large scale in the Lothians of Scotland, "commercial practice has expanded its meaning to include all manner of materials from which mineral oil can be obtained by distillation. Consequently it is now applied to a number of cases which lithologically are not shale, and which differ from the Scottish type also in the nature of their organic matter, and, consequently, in the character of the oil obtainable from them."

According to Conacher, a reduction in the amount of mineral matter of a shale of the Lothian type results in its gradual change into a torbanite.

Another Resolution which was passed at the Plenary Meeting was a Recommendation to the Institute of Petroleum to consider the question of holding a similar conference on oil shale and cannel coal within the next ten years. It is gratifying to find that in less than two years from the date of the Conference held in Scotland, a serious effort has been made by such eminent workers in this field as Dr. Down and Dr. Himus to establish a system of universal nomenclature for oil shales and cannel coals. Whether their attempt will meet with universal approval or not remains to be seen.

The Institute of Petroleum in publishing this paper is making a step forward to the securing of a standard nomenclature. The authors have avoided, in their system of names, those which have been widely misused hitherto, and instead have employed terms which are descriptive of the main constituents of the materials.

Whilst many may agree with the authors that it would be advantageous to avoid using such names as "oil shale," "cannel coal," etc., the fact remains that these names have been in local and general use for so long that it is doubtful whether even prohibition by an Act of Parliament would prevent people from using them, including those who know that true oil shale contains no oil as such, but only produces oil when the organic matter it contains (kerogen) is subjected to destructive distillation by heat, and those who know that no "cannel coal" is to-day being used for the production of smoky luminous flames resembling the early "candles" when burning.

The authors boldly propose an entirely new nomenclature, to be based on the nature of the plant remains and on the nature of the mineral matter (where important), prefixed by an adjective explanatory of the locality from which the material was obtained. Thus Scottish oil shale becomes "Broxburn main kerogen shale Scotland," the Esthonian oil shale kukersite becomes "Esthonian algal limestone," South African Ermelo torbanite becomes "Ermelo algal shale," and so on.

It is difficult to see how the authors would discriminate between "Torbanehill mineral" (torbanite), "boghead cannel," and "parrot coal," in all of which the algal content is high. It will be remembered that the first two names became of historic interest on account of the controversy which arose concerning the nature of the materials in 1853 and which led to a lawsuit.

Professor Hickling, who examined a very large number of cannels microscopically, found what he termed a typical cannel to consist of "very small shreds of vitrain-like material, in laminar structure, and to differ from durains by almost complete absence of algæ, but by the presence of spore exines, cuticles and resins in some quantity." From this, Dr. Mott concludes that it would appear that the source of oil from typical cannels may be the resinous matter present. Mr. Skilling points out that the material which Professor Hickling regards as a typical cannel will not burn with a smoky luminous flame, such as has always been regarded as a characteristic test for a cannel coal.

It is to be hoped that the authors will carry out more detailed work in the near future on the lines of the present paper, in order to bring other oil-yielding materials into the classification they have outlined, and particularly those of Class I, which includes the oil sand, tar sands, and bituminous limestones which have not been included in the paper.

They have done a real service by including at the end of their paper a tabulated classification of many kerogen rocks and kerogen coals, showing their inter-relationship and their gradations into bituminous coals. In this table they give the names commonly used at present, side by side with the new names now proposed for them in this system of nomenclature. As this classification gives, for the first time, a rational and scientific definition of the present names is there really any need to avoid the use of these old names, provided they are only used as defined by the authors of this valuable paper? Surely the proposed nomenclature should prevent misapplication of the old terms in future.

Mr. J. McConnell Sanders (*Asiatic Petroleum Co.*): Scientific classification has been defined [1] as "the formulation of a scheme of mutually exclusive and collectively exhaustive categories, based on the most important characteristics of the things concerned, and the actual relations between them."

For practical reasons this definition requires amplification so as to indicate the means whereby the important characteristics referred to may be ascertained and compared. This becomes of increasing importance when specific terms are employed in the classificatory nomenclature which are not self-explanatory.

Before commenting upon the very comprehensive system outlined by Down and Himus, it should be pointed out that the resolution passed by the Plenary Session of the Conference on Oil Shale and Cannel Coal in 1938 invited the Institute of Petroleum to consider the nomenclature of the various oil-producing materials discussed or described in the various papers submitted to the Conference.

With the exception of cannel, no varieties of coal entered into the deliberations of the Conference, hence the extension of the now proposed scheme so as to include the classification of coals of the peat–anthracite series is somewhat outside the scope of the original invitation.

Moreover, the classification of coals has already been the subject of consideration by other International Conferences, and according to Redmayne [2] the best of these classifications was that adopted by the International Geological Congress held at Toronto in 1913.

Under this scheme coals were divided into four main classes and three sub-classes, and it included not only cannel, but also lignite and brown coal. It is not proposed to discuss the merits or demerits of the Toronto scheme, the basis of classification being entirely different from that proposed by Down and Himus.

Nevertheless, the suggestion by the latter that the classification of oil-yielding materials should comprehend coals which under certain conditions may be said to also yield oils is entirely rational, and worthy of careful consideration.

As is well known, low-temperature coal tars, and especially vacuum tars, contain constituents which are identical with substances found in petroleum, and whereas a high-temperature tar is mainly aromatic in character, a low-temperature one is paraffinoid.

It is therefore necessary to closely define the conditions under which oil is produced

by heat treatment if, as proposed by Down and Himus, their Class II (oil shales) are to be defined as "substances which yield 50 per cent. or more of their organic matter as *oil*," and are thus to be distinguished from Class III materials which yield only 15 per cent. as *oil*.

It is true that these definitions are taken in conjunction with the relative solubility of the organic matter in "normal solvents for petroleum," but the latter expression is somewhat ambiguous, both as regards the nature of permissible solvents and the conditions of extraction. As will be noted later, heat treatment of the material before application of a solvent might be considered a legitimate method of ascertaining the nature of the organic matter present.

There would appear, however, little difficulty in settling these details of practical procedure and adopting the primary classification into three main classes. As regards nomenclature, it is noted that it is proposed to abandon the names "oil shale" and "cannel coal," the first on the ground that it is misleading, and the second because it gives no indication of the nature of the material.

On the other hand, both these terms are very firmly established, and it would be difficult to replace them; neither should it be necessary if their misuse could be obviated by a more precise definition of their own meaning or that of the terms to which they are frequently misapplied.

Oil shale is perfectly well understood by technologists to mean "a shale capable of yielding oil" and it is no more misleading than such terms as "oil seed," "oil cake," and "oilstone," in which three distinct meanings are attached to the word "oil" and only one of the substances concerned is understood to contain oil as such.

Again, it might be contended that the term "cannel," if its derivation from "candle" is accepted, does in fact indicate the nature of the material, or at least one of its properties. Apart from this, cannel comes under Class C of the Toronto classification of coals, and thus earns the right to retain its place amongst technological terms.

Actually there is a vast number of accepted terms in technology which give no indication of the nature of the material to which they are applied, and yet are useful and convenient as type designations in a classificatory scheme.

It is suggested that the proposed alternative terms "kerogen rock" and "kerogen coal" should preferably be employed in the adjectival form, since kerogen is a substantive; and that the primary classification should be modified so as to adapt itself to the classification of sedimentary rocks suggested by H. B. Milner.[3]

Thus the latter's main group "B" (Rocks of organic origin) could have its fourth sub-division "B_4" (Carbonaceous rocks) changed as follows:—

B_4. Rocks yielding oil or tar by destructive distillation.

$B_4$1. Bituminous Rocks.		$B_4$2. Kerogenous Rocks.		$B_4$3. Carbonaceous Rocks.	
Character.	*Type.*	*Character.*	*Type.*	*Character.*	*Type.*
Arenaceous	Oil sands Tar sands	Calcareous	Kukersite	Anthracitic	Anthracite and semi-anthracite
Calcareous	Bituminous limestone	Argillaceous	Scottish oil shales Tasmanite	"Bituminous"	Bituminous coal
Argillaceous	Oil-bearing shales	Calcareo-argillaceous	Kohat oil shale	Kerogenous	Cannel coal
Asphaltic	Native asphalts Gilsonite	Sapropelic	Torbanites Bogheads	Lignitic	Lignite Brown coal
				Sub-lignitic	Peat

The practical application of this scheme as a preliminary sorting test does not require a very elaborate procedure. All the sedimentary rocks considered yield oil or tar by distillation; those in Group $B_4$1 are distinguished from those in the other two groups by the greater solubility of their organic matter as proposed by Down and Himus. Group $B_4$2 differs from $B_4$3 in that carbonization or "coalification" has advanced to a greater degree in the latter. Thus black cannel is considered as a kerogenous coal, whereas the lighter-coloured types of cannel which may contain a relatively larger proportion of preserved organic remains (kerogen) are considered as Sapropelic kerogenous rocks.

The secondary classification proposed by Down and Himus is based on the assumption that the organic remains, which constitute the kerogen in some of these oil- and tar-yielding minerals, can be readily and definitely identified as either algæ or spores.

It is true that the work of Blackburn and Temperley has shown most convincingly that the "yellow bodies" in a number of cannels and bogheads are the remains of an alga very similar to the living *Botryococcus Braunii*, but the position regarding the identification of other organic matter as spores is not so clear cut.

As pointed out by Stopes and Wheeler,[4] a group of crushed, semi-decayed, or bacteria-invaded spores may simulate other plant remains or algæ of various sorts. It is also possible, especially in the case of microspores, that thick-walled resting spores of algæ are alone preserved, or partly so, in which case the material containing them should rightly be designated as "algal."

There is a further objection to the use of the term "algal" when applied in connection with sedimentary rocks, in that it is liable to be confused with the same term as commonly employed to designate rocks, built up of or containing fossilized or mineralized algæ.

Thus Down and Himus use the term "algal limestone" to classify rocks of the Esthonian Kukersite type, but among petrographers the term is used to classify limestones which contain or are made up of the remains of such algæ as *Lithothamnion* or *Chara*.

Even the more general term "algal rock" might be criticized from this viewpoint, for, according to Solms-Laubach,[5] undoubted *Lithothamniæ* are abundant throughout the series of Tertiary deposits, and in some localities form almost the entire material of thick layers; they compose the granite-marble of the Nummulitic rocks.

The question arises whether it is necessary or desirable to attempt such a fine distinction between algæ and spores as being respectively indicative of distinct types of kerogen. The past history of investigations relating to the latter shows only too clearly that the practical identification of the "yellow bodies" has been a matter of such difficulty that even experienced observers have been content to adopt Crum Brown's indefinite term, or something equally noncommittal.

Sometimes bodies of spore-like appearance have been described as resins, the description being subsequently abandoned on the ground that they were insoluble in the usual resin-solvents. Although in some cases the actual organized remains have been identified as spores or algæ, it is worthy of note that resinous matter might well have been present, since several fossil resins are known to be insoluble until they have been heat-treated, and it is a well-known fact that the amount of organic matter removable by solvents from kerogenous material is increased by heat treatment.

Engler [6] states that certain insoluble "bitumens" become soluble after heating; Vignon [7] showed that the amount extracted from coal by treatment with pyridine, aniline, and quinoline increased in the same order as the increase in boiling point of the solvent, whilst McKee and Lyder [8] hold the view that the decomposition of kerogen by heat to form oil takes place in two stages, the insoluble kerogen being first converted into a soluble form which is unstable towards heat, this on further heating giving oil of the petroleum type of higher saturation and greater stability.

The present writer has found resin droplets, in the insoluble form, present in several varieties of crude petroleum, and often accompanied by spore cases, partly decomposed plant debris, and algal remains. Sometimes there have been found in the same crude oil fragments of woody tissue in which the cells lining schizogenous resin cavities were perfectly preserved, whilst resin was found dissolved in the oil.

Resinous matter in coals, cannels, and lignites has been the subject of extensive investigation, and it appears to be the consensus of opinion that resin, waxes, and higher fatty acids have exercised some kind of protective function in preserving the cuticles, spore cases, pollen exines, bark, and cork which are found in carbonaceous rocks.

These considerations seem to point the way to the conclusion that the real kerogen—the oil-former—does not entirely reside in the cuticular skeletons of algæ, the outer coatings of spores, or the relics of plant tissue, although these organic remains may contribute to the composition of the oil or tar produced by distillation.

In fact, as a basis for classification, it would appear that spores and algæ, or any other embalmed organic remains, are not mutually exclusive nor collectively exhaustive designations: they represent only the symptoms of the oil-yielding propensity in the materials concerned, not their primary cause.

In apparent opposition to this opinion, Blackburn and Temperley,[9] as a result of experiments on recent, dried coorongite, showed that whilst oily and waxy material could be extracted by solvents, the relatively insoluble residue could be presumed to be capable of yielding "paraffin products" by destructive distillation.

They also refer to the fact that cannels may or may not contain "yellow bodies," but when these do form a large proportion of the coal it becomes more valuable as a source of "paraffin" than of gas.

There appears to be an implied distinction between "paraffin" derived from cannel coal and "paraffin products" from recent coorongite, the latter presumably referring to any members of the paraffin series from methane upwards, the former to the wax which can be obtained by re-running the crude distillate and chilling the pressible "cut."

In either case these authors would seem to favour the hypothesis that oil is derived from the algal skeletons rather than from the matrix which surrounds them in the mineral. Whilst it is true, as shown by Legg and Wheeler,[10] that a modern cuticle (*Agave americana*) *gave* about 60 per cent. of vacuum tar containing hydrocarbons, and fossil cuticle from Russian paper coal gave about 20 per cent. less, the former was easily attacked by alkali, the latter only slightly, and thus, while accounting for the formation of hydrocarbons by the destructive distillation of cutin and accompanying fatty acids and waxes, the existence of sulphur and nitrogen compounds in the resulting oil is not explained.

If original cell contents are assumed to accompany the algal skeleton or spore coats in the kerogen, then not only sulphur and nitrogen, but perhaps the phosphorus which is found in the ash can be accounted for.

In this connection it is interesting to note the analysis of Balkash Sapropelite (presumably *Botryococcus*) given by Zelinsky.[11]

The latter states that 39 per cent. of the material is soluble in carbon tetrachloride, the extract containing free fatty acids and their esters. The organic matter is stated to have the following composition :—

	%
Carbon	73·76
Hydrogen	10·61
Sulphur	1·03
Nitrogen	0·56
Phosphorus	trace
Oxygen	13·74

In the case of Tasmanian oil shale, Kurth and Rogers [12] state that nearly, but not quite all the oil yield is produced from the amber-like bodies, which they suggest are not spore cases, but the spores themselves fossilized. They further state that the shale, freed from spore cases, produces some oil, but that the gas produced during distillation is free from hydrogen sulphide. The entire shale is shown to yield both ammonia and sulphur compounds.

In view, then, of the difficulty in establishing the identity of the "yellow bodies" in all cases, and because it is not yet established that kerogen is exclusively represented by algæ and/or spores, it is suggested that the latter terms are not entirely satisfactory for purposes of classification.

For practical purposes there is much to be said for a nomenclature which is self-suggestive of properties which are readily discernible or easily ascertainable. Many of the descriptive terms already commonly employed in the industry are of this nature, but confusion has arisen because materials having a single, or at best a few, physical properties in common have been designated by the same term.

Sometimes the misapplication has been in respect to the mineral component of the material, whilst in others it is the organic attribute which has been wrongly designated.

It was suggested by Macgregor [13] that the nomenclature should take into account such factors as appearance, structure, oil-yield, and ash content, whilst Roberts [14] affirms that if any attempt were made to simplify the nomenclature of cannels, attention should also be given to their coking propensities.

It may be suggested further that in gathering material for the purpose of classification more attention should be given to the possibilities of the minerals which accompany the kerogenous materials, and which may be recognized by petrographic methods or detected by chemical analysis.

Amongst the latter, certain elements, such as vanadium, nickel, and to some extent aluminium and magnesium, may have a special significance in relation to the organic constituents of the material.

For instance, Tasmanite contains as kerogen, bodies which are supposed to be the

preserved spores of lycopodium. Since the *Lycopodineæ* are quite remarkable for their high aluminium content, and since the spores are large and easily separated from the mineral matrix, the estimation of aluminium in their ash would appear to have more value than the analysis of the bulk mineral.

References to contribution of Mr. McConnell Sanders.

[1] Wolf, Abraham, "Encyclopædia Britannica," 14th Edition, Vol. 5, p. 778.
[2] Redmayne, Sir R. S., *ibid.*, "Coal and coal mining," pp. 868–903.
[3] Milner, H. B., "Sedimentary Petrography," 1929.
[4] Stopes, M. C., and Wheeler, R. V., "The Constitution of Coal," D.S.I.R. Monograph, 1918.
[5] Solms-Laubach, H. Graf zu, "Fossil Botany," English translation, 1891.
[6] Engler, C., *Das Erdöl*, 1917, 1, 35.
[7] Vignon, L., *Compt. rend.*, 1914, 158, 1421.
[8] McKee, R. H., and Lyder, E. E., *J. Ind. Eng. Chem.*, 1921, **13**, 613 *et seq.*
[9] Blackburn, K. B., and Temperley, B. N., *Trans. Roy. Soc. Edin.*, 1936, **58**, 841–868.
[10] Legg, V. H., and Wheeler, R. V., "Safety in Mines," Res. Bd. Paper No. 17, 1926, and *J. chem. Soc.*, 1925, **127**, 1412.
[11] Zelinski, N. D., *Brennst.-Chemie*, 1925, **6**, 365–369; 1926, **7**, 35–37.
[12] Kurth, E. E., and Rogers, L. J., "Oil Shale and Cannel Coal," 1938, pp. 193–209.
[13] Macgregor, M., *ibid.*, pp. 8–17.
[14] Roberts, J., *ibid.*, p. 39.

Dr. M. Macgregor (*Geological Survey*): In a paper communicated to the Conference on Oil Shale and Cannel Coal held at Glasgow in 1938 I emphasized the desirability of securing, if possible, a standard nomenclature for the various oil-yielding materials included under the designations cannel, boghead, etc. I had in mind the difficulty experienced by the field worker in the lack of any standard series of categories to which to refer, and the fact that terms such as oil shale and cannel were used for materials differing widely in mode of occurrence, origin, and composition. Thus the term oil shale, long employed in Scotland in connection with the Lower Carboniferous shales of the Lothians, has been used to designate oil-yielding materials of many different kinds and ages. It has been used, for example, for the torbanites and cannels of New South Wales (Permo-Carboniferous); for the spore-rich "tasmanite" of the Mersey River Valley in Tasmania, regarded as a shallow-water marine sediment probably of Permo-Carboniferous age; for the Estonian "kukersite," a marine deposit of Ordovician age; for the "marahuito" of Bahia in Brazil, a somewhat variable material of algal origin, allied to torbanite (Cretaceous or Early Eocene); for the black carbonaceous shales of the Eastern United States (Devonian); and for other deposits of varying character in different countries. The term cannel, again, includes materials of different composition and widely different economic value. In putting forward my suggestion I envisaged the appointment of a small committee to examine and report upon the question, just as the British Association Committee on petrographic classification appointed in 1932 examined and reported on the nomenclature of igneous rocks. The authors of the paper now presented have boldly tackled the problem of both the nomenclature and the classification of the naturally occurring oil-yielding materials. Their nomenclature is based on the dominant plant and mineral constituents present and the classification is put forward merely as "a foundation on which further classifications can be developed as our knowledge of the chemistry of these materials increases." It is very doubtful, however, if the proposed nomenclature will be acceptable to those who have to deal with the raw materials in the field and laboratory. The introduction of such terms as "kerogen rocks" and "kerogen coals" appears superfluous. Nor does it seem in the least necessary to discontinue the use of such long-established names as oil-shale and cannel. It should be quite possible to retain these names for definite groups of oil-yielding materials, and to subdivide these further according to their essential macroscopic and microscopic characters. Cannels are micro-fragmental coals and form a graded series ranging from the richly algal brown and black bogheads, through algal-spore cannels with increasing proportions of decomposed plant debris forming a bright transparent groundmass, to canneloid shales containing a high proportion of inorganic matter. It should be quite possible to define the series brown boghead, black boghead, boghead-cannel, cannel, canneloid shale not only in terms of decreasing oil-yield, but also in terms of macroscopic and

microscopic characters. The macroscopic characters used would include colour, lustre, fracture, streak, structure, etc. As regards the broad classification, the writer would prefer to see some such twofold grouping adopted as (1) Oil Shales; (2) Cannels (and Cannel-coals) excluding from present consideration bituminous coals which are looked upon as tar-providing rather than oil-bearing materials.

The problem is to find a simple and convenient classification based (*a*) on field observations and (*b*) on microscopic examination in the laboratory. The following might be tentatively suggested :—

- Oil Shales
  - Calcareous
  - Argillaceous
    - Algal
    - Spore-rich
- Cannels
  - Canneloid shales—high content of inorganic matter
  - Cannel coals—plant debris and spores, with a varying amount of algal remains
  - Bogheads—largely algal

Obviously this is only a skeleton classification, and in defining the different categories such criteria as mode of occurrence, nature of associated strata including position in the sedimentary cycle, should be taken into account, as well as the other characteristics already enumerated.

Dr. L. Slater (*Fuel Research Coal Survey Laboratory, Sheffield*): We appreciate that the older term "cannel" has been used for a large variety of substances, both rich and poor in "oil-yielding" properties, and hence might with advantage be superseded by more precise terms such as those suggested. In using the new terms, however, it will have to be clearly borne in mind that the substances referred to form a continuous series, without sharp distinctions.

Most of the suggested terms have the merit of being self-explanatory, but "algal rock," although scientifically quite sound, is perhaps doomed to unsuccessful competition with the older and unscientific "boghead." "Algal rock" might be confused with "algal shale" unless structure was described each time the terms were used.

As the classification given in the paper is based on the three main groups "Kerogen rocks," "Kerogen coals," and "Coals," it seems very important that the meaning of the term "kerogen" should be made clear. On p. 331 the term is applied to "unresolvable masses of macerated plant debris containing a few spores and/or algæ." But if this is accepted as a definition, it follows from our experience that *all* coals contain very considerable amounts of kerogen. Would it not be better to exclude the unresolvable debris, and define kerogen as a collective term for spores and/or algæ only? This would make it roughly synonymous with the "Protabitumina" of the German petrologists, and also would be more in accord with the classification scheme given at the end of the paper.

We have encountered some samples of bright coals composed of fragments so finely divided that the usual banded appearance is practically absent. Such material is often considerably richer in volatile matter than the more normal material from the same seam, although microscopical work shows it to contain no algæ and no abnormal quantity of spores. Whether such material should be classified as a type of "kerogen coal" will thus depend entirely on a more precise definition of "kerogen."

Dr. R. A. Mott (*Department of Fuel Technology, University of Sheffield*): The Classification proposed does not do full justice to special types of coals which are important for their oil-yielding capacity. It assumes that algæ and spores alone are the cause of the oil yields of cannel coals, and ignores the important part played by resins and resinous materials in this connection.

In the discussion on the paper by Mr. W. J. Skilling on "The Nature of Scottish Cannels" (*Oil Shale and Cannel Coal*, 1938, p. 40), I directed attention to the fact that Scottish cannels differed in composition from cannels examined by Professor Hickling and from those examined in other laboratories by Dr. W. A. Chao and by Dr. Holroyd. The *ordinary* cannel coal found associated with bituminous coal seams in England appears to conform to Hickling's description, and algæ are absent and spore exines, cuticles, and resins are present in some quantity. In the six cannels examined

by Dr. Chao (a reprint of whose paper is enclosed) spores occurred only rarely, and the high oil-yielding properties were apparently due to a degraded resinous material.

Since fossil resin is found in lump form in many of the Japanese coals of Tertiary age (which have hydrogen content exceeding 6 per cent.) and in the Washington U.S.A. coals of the same age (which usually contains about 6 per cent. of hydrogen), and in young New Zealand coals this confirms the knowledge that the coniferous trees only developed in more recent geological periods. A place should be found for such coals in Table 7. I suggest that, under "Kerogen coals," p. 335, the title be altered to "spores, resins and macerated plant debris," and alongside the term "Spore Coal" be placed the term "Resinous Coals," examples of which are given above.

To these should be added cannel coals free from algæ and spores such as are described by Dr. Chao.

I suggest that it might also be proper to include the term "Cuticle Coal," an example of which is the *Papier Kohle* of Russia described by Legg and Wheeler in *J. chem. Soc.*, 1929, 2449.

Under the heading "Coals" below the statement "Vegetable debris generally accumulated *in situ* sometimes drifted" should be placed an arrow pointing to the Kerogen coals with the expression "Increase in proportion of drifted material." I suggest also that the term "organic residue" in the ratio of oil yield/organic residue requires definition. It appears to refer to an organic residue on heating to 500° C. Also the statement below this that "oils obtained by carbonization . . . generally contain upwards of 30 per cent. of material soluble . . ." should be altered to "up to 30 per cent."

Dr. H. B. Nisbet (*Heriot-Watt College, Edinburgh*): Dr. Down and Dr. Himus have done a great service in suggesting suitable generic terms to which can be referred substances commonly called oil shales and cannel coals. With regard more particularly to the latter group of substances and the closely related torbanitic shales, what is now required is a study of the various grades of material which will fall under the heads of kerogen coals and algal shales with the object of setting up standards for suitable sub-divisions. While such sub-divisions might be arrived at, as has been suggested by the authors, by microscopic examination, it is to be hoped that this will be correlated with fundamental chemical investigations. The kerogen coals or cannels (and algal shales) occur in a large variety of physical forms and are associated with widely differing amounts of mineral matter of varying composition. They possess occasionally fairly well-developed coking properties and at other times none at all, and they yield varying amounts of oils of differing characteristics on destructive distillation. It would be well, therefore, if a large number of deposits from various localities were fully investigated microscopically and chemically. Much information would doubtless also be obtained by suitable solvent extraction, and it would be of special interest to know if the constituents producing coking properties have any relation to the components causing this in ordinary coking coals as tracked down by Bone's benzene-pressure extraction method. A correlation of a large amount of data on such subjects would be extremely useful and would no doubt provide material on which a sub-classification could be built.

In 1924 Dr. E. F. Armstrong, in his Presidential Address to the Society of Chemical Industry, made the suggestion that the chemistry of fatty oils had not received the attention it deserved. During the intervening years we have seen great advances in our knowledge of this subject, largely due to the investigations of Prof. Hilditch and his school of research at Liverpool. It would appear that kerogen shales and coals offer a subject for fundamental research of a somewhat similar range, and it would be highly gratifying if the Glasgow Conference of 1938 and the paper now presented by Dr. Down and Dr. Himus provided the stimulus to start an investigation of this character.

Mr. W. J. Skilling (*Fuel Research Coal Survey Laboratory, Glasgow*): It is interesting to note that the authors are endeavouring to keep alive the resolution passed at the Conference on Oil Shale and Cannel Coal held in Glasgow in 1938.

The difficulty of arriving at a satisfactory grouping or system of nomenclature for such naturally occurring materials as oil shales, torbanites, and cannel coals is the merging of one into another. One may receive a number of hand specimens which to

the eye of the field geologist are identical, but when examined in the laboratory by the chemist yield oils in varying quantity and of widely different chemical composition.

When the Boghead cannels or Torbanites are encountered, their identification presents little difficulty in the hand specimen. They invariably have a brownish shade of colour, are tough and difficult to break, and have a characteristic wooden sound when struck. The Lower Dysart Cannel of Fife possesses all the characteristics of a Torbanite—so much so that to apply the name "coal" to it is quite misleading.

The group of materials in which the hand specimens are almost indistinguishable but which in microsection show pronounced differences are the black, satin-surfaced cannel coals. These differences are also reflected in the varying oil yields obtained; thus the writer has observed that when algæ are easily identified in a specimen a high yield of oil has been found, but when they are difficult to detect in the finely macerated plant debris the yield approaches that of a bituminous coal and is more of a tarry than oily nature, having more oxygenated constituents and no indication of wax.

The authors have referred to the Humph Seam cannel as a spore coal and to the specimen from New Cumnock as an intermediate algal-spore coal. Based upon laboratory examination the writer would classify neither of these materials as spore coal, since spores form a very minute proportion of the plant debris. Typical spore coals are found forming bands in certain of the splint coal seams of Scotland and are described as durain. The spores are in such high concentration as to be visible without the use of a lens. Such coals have a matt or granular surface, as compared with the smooth, satiny surface of a cannel coal.

From experience in handling specimens, and from discussions with geologists and mining engineers, the writer is of the opinion that it would add to the existing confusion to introduce the terms "algal" and "kerogen" to the exclusion of the widely used "oil shale" and "cannel." Most of this confusion has been due to a tendency of some authors of papers on these materials to coin new words based upon the result of a laboratory examination of a limited number of specimens.

The whole problem of nomenclature centres round whether the geologist, the mining engineer, or the chemist should have the privilege of deciding upon the most appropriate name for these products of nature. It is for this reason that the writer would suggest the formation of a committee representing these professions and drawn from each of the coalfields of this country to discuss and decide upon a nomenclature for oil shales and cannel coal. Some representation of those foreign countries which produce and utilize these materials should be invited.

Mr. R. J. Forbes (*N.V. de Bataafsche Petroleum Mij*): The authors are greatly to be commended for their effort to evolve, in spite of the comparatively unknown nature of the subject, a classification of these materials, and for their introduction of a series of names, which will undoubtedly facilitate discussion. The future development of a scientifically sound classification and nomenclature will be greatly assisted thereby.

As regards the last line of paragraph 1, page 330, it would perhaps be better to alter this to read "only about 15 per cent. of the organic matter as oil *on heating*."

In the table immediately below this paragraph I suggest that the words "bituminous rocks" be substituted for the list of oil-yielding materials given under Class I, since this list is, in any case, not complete. If it is desired to extend the list or to use it to supplement the table given as addendum to the paper, the authors would do well to consult the book by H. Abraham, "Asphalts and Allied Substances" (4th ed., New York, 1938, Chapter II), in which the classification of bituminous materials is dealt with in detail and from which a provisional system of classification and nomenclature could be derived.

I regret that I cannot entirely agree with the arrangement of the group "Coals" in the table appended to the paper.

The fact is that in the different kinds of coal durain, clairain, and citrain occur in variable quantities; these components of coal, thus, do not correspond with what is understood by Spore Shale, Algal Limestone, etc., in the same line of the same table. The question thus arises whether it is perhaps desirable that the classification should be extended, *e.g.*, according to the system of Jongmans, set out in detail in the book by D. J. W. Kreulen, "Grundzüge der Chemie und Systematik der Kohlen" (Amsterdam, 1936), which book further treats extensively of the materials in question. In this way the difference between cannel coals and Class II, Kerogen Rocks and Oil Shale, could also be more clearly brought out.

A brief indication of the methods by which solubility in various solvents, oil yield on heat treatment, etc., are determined would also be of interest, since the figures for the various materials given here are difficult to compare owing to differences in procedure.

I hope that the authors will regard these minor criticisms as a small contribution of building material towards the edifice of systematization of these materials which they are now, in so praiseworthy a manner, attempting to construct.

Mr. John Roberts (*Consulting Fuel Technologist*): I should like to refer to page 332, para. 5 of the paper, where it is proposed to classify three types—namely, algal coals, algal shales, and algal rock. The difficulty here is that *all three* are algal rocks, and could be properly described as such. If "algal rock" contains organic matter which consists "almost entirely of algæ," perhaps the term *algite* would be suitable.

As the object of the Resolution was to standardize terminology, exception will be taken to the rather loose use of the term "mineral matter" in the paper. For example, "the mineral matter consists of clay. . . ." Clay is not a mineral, but a rock (page 332, para. 4).

Professor A. E. Trueman (*The University, Glasgow*): The authors are to be congratulated on their courage in tackling the difficult problem of the classification of oil shale and cannels. They have brought together a quantity of useful data which will be of great value in any discussion of the problems arising in the classification of these materials, although I am not convinced that the general scheme of their classification is likely to lead to any real clarification of the problems with which we are concerned. In the first place, if we divide the materials into two main groups corresponding to those which the authors have named the kerogen rocks and kerogen coals, I would suggest that "kerogenous rocks" and "kerogenous coals" would be more euphonious terms and more in keeping with the general character of petrographic nomenclature. The separation of these two groups, however, does little more than re-emphasize a distinction which has been fairly widely made, and discussion must be concerned mainly with the subdivisions which have been proposed.

I am bound to direct attention to the fact that the term "algal limestone" can scarcely be maintained as a type of kerogenous rock, since this name is customarily and widely used for a purely calcareous rock consisting mainly of the remains of calcareous algæ and having no relation to the materials considered here. I feel, also, that there is an objection to the use of the term "algal *rock*" as a type of kerogenous *coal*; it is surely inconsistent to use the word "rock" in the classification of this group, as it does not appear in the classification of the kerogenous rocks themselves.

The proposed names for individual rock types, such as Esthonian algal limestone in place of Kukersite and Tasmanian spore shale for Tasmanite, can scarcely be regarded as contributing to a classification, although for the present they may lead to more precision in the discussion of the materials. For the term "Kukersite" is available for any similar material, and its use for material from other localities than Esthonia would, if it is employed with a suitably restricted meaning, immediately convey the correct information about the deposit. But under the author's scheme the term "Kukersite" would disappear, and every individual locality would attach its name to the material under discussion.

These, however, are purely matters of terminology, and it appears to me that criticism of the authors' classification may go rather deeper than terminology. I wonder whether a satisfactory classification of such variable materials can be made on the basis of a more or less linear series. Since consideration must be given to variations in amount and character of organic material as well as to variations in amount and character of the inorganic materials, a more extended range of criteria is surely desirable. Moreover, it is necessary to have some indication of the range of compositions over which these terms can be applied; for example, while the proportion of kerogen in an oil shale may be over 50 per cent., there is presumably a continuous passage into shales with no kerogen. At what point in the series does a rock cease to be a kerogen shale? Is it to be determined by the percentage of organic material present, or by the amount of oil yield?

I am sorry to see the use of the term oil shale is not approved: whilst "oil shales contain no oil as such," however, it may also be noted that lead ore contains no lead "as such," but it is nevertheless lead ore.

Dr. A. WADE (*Australia*): From a scientific and technical point of view I regard this paper as an excellent contribution on the question of classification. From a practical, working standpoint I am afraid that it will have little effect. Those who have to work mines in these materials and who have to deal with miners will go on using the old names to which they have long been accustomed, regardless of all that may be written on the subject. The Australian miner will still call the rock which is now being mined on a large scale in the Wolgan Valley—Oil Shale. So will the Tasmanian who mines Tasmanian Spore Shale.

This will not, I am sure, discourage the authors. Research students will welcome and use the classification. Possibly they may upset it in due course. They usually do.

Authors' Reply to the Discussion.

In 1936 a comprehensive research on the chemistry of oil shales and related materials was instituted at the Fuel Laboratories of the Imperial College. The investigation has for its primary object the elucidation of the chemical constitution of the organic matter in sedimentary rocks from which oil is obtainable by heat-treatment. A number of samples were obtained, covering wide geographical and geological ranges, all of which had two common properties: (*a*) that all gave a good yield of oil when retorted at 600° C. and (*b*) the yield obtained by Soxhlet extraction with organic solvents was low; in other respects, however, the samples were widely different. Initial search of the literature showed that the nomenclature of the various types of oil-yielding materials was in a state of confusion, and there was no systematic classification, so that samples could be readily identified, and hence correctly named. In view of the comprehensive nature of the researches envisaged correct nomenclature of the samples examined was particularly important.

It had been hoped that at the Oil Shale and Cannel Coal Conference in 1938 that the problems of the classification and nomenclature of these materials would be clarified. A number of authors directed attention to the urgent need of a standard nomenclature, but no constructive proposals were put forward until the Plenary Session when the resolution quoted at the beginning of this Paper was adopted.

Concurrently with the chemical investigations, the authors examined thin sections of the samples and collected all the available geological data. Whereas a chemical classification analogous to that adopted for coals could not be attempted owing to the lack of reliable data on the composition of the kerogen of a sufficient number of samples, it was found possible to suggest the petrological classification set out in this paper. Further, since the question of nomenclature had not been tackled, the system employed in the classification table was worked out and put forward with the object of stimulating interest and promoting the establishment of a satisfactory system. It was not anticipated that the suggestions would be allowed to pass without criticism, and it is gratifying to find that, even in the present circumstances, considerable interest has been aroused by the proposals.

Captain W. H. Cadman and Professor A. E. Trueman both directed attention to a difficulty which arises in any classification such as that described—namely, that it is quantitative, and not purely qualitative. The same argument applies to the classification of coals of the peat → anthracite series. It is quite easy to define an "algal rock," "algal coal," and "algal shale," but borderline samples are met with and their final allocation will depend to some extent on the opinion of the observer.

Dr. L. Slater points out that it is desirable that the term "kerogen" should be accurately defined; to this everyone will agree, but in the present state of our knowledge, any precise definition is practically impossible. Kerogen is a sedimentary material, formed (apparently) almost exclusively of the remains of plants and consisting of compounds of carbon, hydrogen, and oxygen, together with usually small percentages of nitrogen and sulphur. These compounds are of unknown, but certainly complex, constitution and high molecular weight. Kerogen is distinguished from the allied carbonaceous materials which form coal by yielding a greater proportion of oil when carbonized at 600° C., and so far as can be ascertained at present, it contains considerably more hydrogen (from 8 to 11 per cent. as compared with 5 to 6·5 per cent. for bituminous coals) for a given carbon content.

Both Dr. Slater and Mr. J. Roberts criticize the name "algal rock" for materials such as Torbanehill Mineral. The very small percentage of mineral matter in these

samples did not warrant its inclusion in the name of the sub-group, and thus the only alternative was a term such as "algite" suggested by Mr. Roberts. The authors, however, wished to avoid coining any new words, the literature being already crowded with such terms, and thus adopted the sub-heading "algal rock."

Messrs. J. McConnell Sanders and R. J. Forbes question the inclusion of bituminous coals in the classification table. This was done because it seemed rational to indicate that there is gradation from the "kerogen coals" to bituminous coals. Further, the two classes are so intimately associated in nature that it was felt that this should be recognized in the table. No attempt of course has been made to include a classification of bituminous coals, since this has already been done by others.

Mr. McConnell Sanders points out that in the terms "oil seed," "oil cake," and "oil stone," the word "oil" has three different meanings. He could scarcely have furnished a better argument for our suggestion that the word "oil" should be absolved from having yet a *fourth* meaning in the term "oil shale."

The objection to the term "algal limestone" on the grounds that it is already used by geologists for calcareous rocks made up of the remains of algæ was not unforeseen. Such rocks are not, however, necessarily *kerogen rocks*, therefore the force of the objection can be done away with if this is made clear.

It is not suggested that kerogen consists exclusively of algæ and/or spores; on the contrary, many kerogen rocks show an almost entire absence of recognizable material, but on carbonization their oil yield is equivalent to more than 50 per cent. of the organic matter. The Kimeridge and Kohat kerogen shales, for example, are practically devoid of recognizable structures, microscopic examination reveals a few pieces of carbonized woody matter or plant remains in a structureless yellow matrix, but, nevertheless, they are true kerogen rocks. On the other hand, J. M. Petrie reported that in the case of the Joadja Creek algal rock, N.S.W., which gave an oil yield of 150 gal. per ton, gelatinous algæ constituted 90 per cent. of the organic matter.

While it is fully realized that the nature of the inorganic matter and its relation to the kerogen require more detailed study, until men and funds are available, the work must perforce be carried out on a more restricted scale than is desirable. Moreover it is important that the problems of classification and nomenclature be cleared up as early as possible in order to further the chemical researches, and to ensure that the nature of the samples investigated is universally understood.

The skeleton classification proposed by Dr. M. Mcgregor is very much on the same lines as that proposed by the authors, except that the terms "oil shale" and "cannel" are retained.

Dr. R. A. Mott suggests that resinous and cuticle coals should be included under the section kerogen coals, such extra sub-headings can always be introduced where the facts, as ascertained by examination of the materials concerned, warrant their introduction.

Mr. W. J. Skilling points out that the questions under consideration cannot be answered by chemists alone; the authors are keenly aware that these individual problems and the whole general problem of kerogen rocks cannot be solved by attacking them from one angle only, the geologist, petrologist, palæobotanist, and chemist are all concerned.

Referring to Mr. J. Roberts' objection to the use of the term "mineral matter" in this paper, all rocks, including clays, are composed of minerals, which justifies calling the "matter other than organic" simply "mineral matter"; as an alternative the term "inorganic matter" could be used.

Professor A. E. Trueman appears to dislike the suggestion that "every individual locality" should attach its name to the material under discussion. The authors cannot agree; it is good petrological practice to state the locality from which a specimen is derived, since precision is thereby given. The name "granite" will probably conjure up as many visions as there are geologists who hear or read the name; each, in fact, will instinctively think of that variety of granite with which he is most familiar, it is the statement of locality which defines the particular variety of granite. Further, the geographical prefixes applied are chosen to represent the whole of a particular deposit, and not localities within the general area of the seam or seams.

Dr. H. B. Nisbet desires that microscopic examination shall be correlated with fundamental chemical investigations; this is precisely the view of the authors, and is at present being carried out at the Imperial College. Progress on the chemical side is necessarily slow, the determination of the percentage and composition of the kerogen

cannot be made by direct analysis, but involves the rather lengthy de-ashing process described in an earlier paper.* The problem of chemical constitution has been attacked by controlled oxidation of the organic matter, with subsequent determination of the distribution of carbon and examination of the oxidation products, an investigation requiring several months. A number of samples have already been treated in this way, but a great many must be examined before any generalization will be permissible, and this will require a number of years to carry out. It was not considered advisable to present the results of chemical researches on a single sub-group of kerogen rocks in a paper dealing with the controversial questions of classification and nomenclature of the whole range of oil-yielding rocks.

* *J. Inst. Pet.*, 1939, **25**, 230–237. A similar method was adopted by J. W. Horner and W. W. Purdy, and a report prepared for the U.S. Bureau of Mines in 1925 but was not published until 1938, as Bulletin No. 415. At the time of publication of the paper on de-ashing the authors were unaware that this Bulletin had appeared.

ERRORS IN ACID-BOTTLE READINGS.*

By G. H. Scott, B.Sc., F.Inst.Pet.

Introduction.

A Teleclinometer survey was recently carried out at one of the wells of Apex (Trinidad) Oilfields, Ltd. The deviations recorded by this method were considerably greater than those obtained by the conventional acid bottle. Three wells had been surveyed prior to this, and had failed to show such marked discrepancies. In these three wells, however, the bit had followed a relatively more vertical course. It was therefore indicated that the divergence between the acid-bottle and Teleclinometer readings increased with the deviation, and the tests that were undertaken, and which are described herein, were carried out to check the correctitude of this supposition.

It was realized that the Teleclinometer readings of deviation might themselves be at fault and, in order to check these, a series of observations were obtained with a single-shot instrument.

The following table gives a comparison of the three sets of observations. Deviations are recorded in decimals of a degree in order to simplify calculations of average figures.

Depth, ft.	Teleclino-meter deviation.	Single-shot.		Acid-bottle.		Acid-bottle difference to tele.	Acid-bottle difference to single shot.
		Depth, ft.	Deviation.	Depth, ft.	Deviation.		
720	4·34°	721	3·50°	721	2·71°	−1·63°	−0·79°
1200	4·67	1205	4·00	1200	2·50	−2·17	−1·50
1450	5·34	1446	4·50	1448	3·25	−2·09	−1·25
1680	5·45	1687	5·25	1685	4·00	−1·45	−1·25
2170	5·10	2169	4·00	2175	2·50	−2·60	−1·50
2410	4·31	2410	4·00	2395	2·50	−1·81	−1·50
2920	5·45	2919	5·25	—	—	—	—

The Teleclinometer deviations at these intermediate points were calculated on the assumption that the deviation between two known readings would be a gradational change. This assumption is considered fair in view of the fact that the drift was in a general eastward direction with no reversals. The single-shot and acid-bottle readings were taken at the actual depths given.

It will be noted firstly that there is much greater constancy in the difference between the acid-bottle and single-shot readings, and secondly that the Teleclinometer readings are constantly higher than the single-shot. A comparison of the two latter readings is given hereunder :—

* Paper read to a Meeting of the Trinidad Branch held on 28th February, 1940.

Depths, ft.	Teleclinometer.	Single-shot.	Difference.
720– 721	4·34°	3·50°	0·84°
1200–1205	4·67	4·00	0·67
1450–1446	5·34	4·50	0·84
1680–1687	5·45	5·25	0·20
2170–2169	5·10	4·00	1·10
2410–2410	4·31	4·00	0·31
2920–2919	5·45	5·25	0·20

If all readings are taken into consideration and it is assumed that the deviation persists to half the distance between any two readings, average weighted deviations can be calculated. For this well they are as follows :—

Teleclinometer	4·85°
Single-Shot	4·36°
Acid-Bottle	2·50°.

It is therefore apparent that although there are some discrepancies between the Teleclinometer and single-shot readings, these are of a minor character in comparison with the very much lower readings obtained by the acid bottle.

Tests.

In practice the acid bottle is lowered in a bill on a wire-line. In this case the readings were taken inside $2\frac{7}{8}$-inch internal flush drill pipe, and the bills used were firstly one supplied by the manufacturers of the wire-line, using a large bottle, and secondly one of local manufacture using a small bottle.

Both bills were used in the tests, and, in order to guard against errors due to divergence of the axis of the bottle-holder from the axis of the bill, the bill was turned through varying amounts between each set of tests.

The true deviation was obtained by means of a plumb bob and an offset scale, and it is estimated that an accuracy of $\pm 0{\cdot}1°$ was obtained.

All acid-bottle readings were recorded by two observers with no preconceived idea of the actual readings, and in several of the tests the bottles were mixed and duplicate readings recorded.

Conditions in practice were followed as far as possible by varying the time of exposure to the acid and by using new and asphalt-filled bottles alternately.

In all, five series of tests were undertaken, and the results are shown in Table I. In recording acid-bottle deviations, "Face-Left" and "Face-Right" readings are taken on each bottle, and the mean recorded. It will be noted that in some cases there is some divergence between the readings recorded by the same observer and also by different observers. It must be admitted that the acid bottle is not a precision instrument, but in the majority of cases there is quite reasonable consonance between the various readings. Fig. 1 shows a small acid bottle drawn to scale, together with lines denoting horizontality and a deviation of 5°. This illustrates in a graphic manner the difficulties attendant on reading an acid bottle accurately to $\frac{1}{4}°$, and the fact that such close correlation was obtained in the readings shown on the table is quite noteworthy.

TABLE 1.

True Dev'n.	Test 1. Small bottle. Local bill.				Test 2. Small bottle. Local bill (turned 30°).					Test 3. Small bottle. Local bill (turned 90°).					
	Obs. 1.	Obs. 2.	Avge.	Diff.	Obs. 1a.	Obs. 1b.	Obs. 2.	Avge.	Diff.	Obs. 1a.	Obs. 1b.	Obs. 2a.	Obs. 2b.	Avge.	Diff.
°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
0·00	—	—	—	—	—	—	—	—	—	0·00	0·25	0·25	0·25	0·19	+0·19
0·75	0·50	0·00	0·25	−0·50	—	—	—	—	—	—	—	—	—	—	—
1·00	1·25	0·75	1·00	0·00	0·50	1·00	0·50	0·67	−0·33	1·50	1·00	0·75	0·75	1·00	0·00
2·00	1·75	1·75	1·75	−0·25	1·00	2·00	1·50	1·50	−0·50	2·25	2·00	1·50	1·75	1·875	−0·125
3·00	2·25	2·25	2·25	−0·75	2·75	2·75	2·25	2·58	−0·42	3·00	3·00	2·00	2·00	2·50	−0·50
4·00	2·75	2·75	2·75	−1·25	3·50	3·75	3·50	3·58	−0·42	4·00	3·75	3·25	3·00	3·50	−0·50
5·00	3·75	3·00	3·38	−1·52	3·50	3·75	3·50	3·58	−1·42	4·50	3·75	3·25	3·00	3·60	−1·40
6·00	—	—	—	—	—	—	—	—	—	4·00	5·00	4·50	4·50	4·50	−1·50
7·00	—	—	—	—	—	—	—	—	—	5·75	5·75	5·25	5·25	5·50	−1·50
7·50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10·00	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

True Dev'n.	Test 4. Large bottle. Wire-line bill.						Test 5.		All-in avge.	Diff.
	Obs. 1a.	Obs. 1b.	Obs. 2a.	Obs. 2b.	Avge.	Diff.	Avge.	Diff.		
°	°	°	°	°	°	°	°	°	°	°
0·00	0·50	0·50	0·50	0·50	0·50	+0·50	0·25	+0·25	0·31	+0·31
0·75	—	—	—	—	—	—	—	—	0·25	−0·50
1·00	0·75	0·75	1·00	1·00	0·875	−0·125	—	—	0·89	−0·11
2·00	2·50	2·50	1·75	2·25	2·25	+0·25	—	—	1·84	−0·16
3·00	3·00	2·625	2·25	2·25	2·53	−0·47	—	—	2·47	−0·53
4·00	2·75	2·75	1·75	2·25	2·375	−1·625	—	—	3·05	−0·95
5·00	3·50	3·75	3·50	3·50	3·56	−1·44	2·25	−1·75	3·47	−1·53
6·00	—	—	—	—	—	—	—	—	4·50	−1·50
7·00	—	—	—	—	—	—	—	—	5·50	−1·50
7·50	—	—	—	—	—	—	6·06	−1·44	6·06	−1·44
10·00	—	—	—	—	—	—	7·56	−2·44	7·56	−2·44

The all-in averages of acid-bottle readings were as follows :—

True deviation.	Acid-bottle deviation.	Difference.	Remarks.
0·00°	0·25°	+0·25°	
0·75	0·25	−0·50	
1·00	0·89	−0·11	
2·00	1·84	−0·16	
2·50	1·56	−0·94	Not recorded on Table I.
3·00	2·47	−0·53	
4·00	3·05	−0·95	
5·00	3·47	−1·53	
6·00	4·50	−1·50	
7·00	5·50	−1·50	
7·50	6·06	−1·44	
10·00	7·56	−2·44	

These points are shown in black in the chart (Fig. 2), and an average line has been drawn through them. The line of true deviation is shown as a dotted line.

This chart indicates a definite tendency to increased divergence between true and acid-bottle readings with increased deviation from the vertical. At low figures of deviation the acid-bottle reading is tolerably accurate, and it is for this reason that earlier Teleclinometer readings showed reasonable

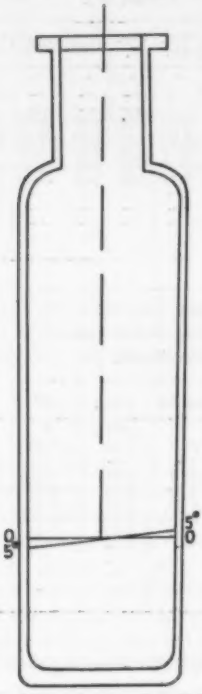


FIG. 1.

correlation with those of the acid bottle. It is interesting, however, to note that even this minor variation is very closely corrected by use of the chart, as is shown hereunder :—

Well.	Weighted teleclinometer deviation.	Weighted acid-bottle deviation.	Corrected acid-bottle deviation.	Difference.
A	1·16°	0·88°	1·20°	+0·04°
B	1·12	0·80	1·05	−0·07

At the time these acid-bottle readings were taken it was the custom to drop the bill down the drill pipe, where it seated in a special sub. The bill was therefore accurately centred in the drill pipe. Now that a wire-line is used for lowering, no sub is provided. It is possible, if not probable, therefore, that the true deviation will tend to be minimized, owing to the

tolerance between the bill and the internal cross-section of the drill pipe. In any case the corrected acid-bottle readings shown on page 349 are still somewhat on the low side in comparison with the readings obtained by the single shot. The single-shot readings have been selected as the instrument was a very close fit with its spring guides in 4½-inch casing.

Depths, ft.	Single-shot readings.	Acid-bottle readings.	Corrected acid-bottle readings.	Difference.
721	3·50°	2·71°	3·50°	−0·00°
1200–1205	4·00	2·50	3·25	−0·75
1446–1448	4·50	3·25	4·20	−0·30
1687–1685	5·25	4·00	5·15	−0·10
2169–2175	4·00	2·50	3·25	−0·75
2410–2395	4·00	2·50	3·25	−0·75
			Average:	−0·44

It is considered, however, that an average error of less than ½° is all that can be expected of the acid bottle.

It is probable that the discrepancy between true and acid-bottle readings of deviation is due to a combination of the following causes :—

(*a*) A tendency to read the etched line low for the higher deviations.
(*b*) Variation of the etched line from that of the original meniscus.
(*c*) Distortion of the meniscus at the liquid/glass contact at the higher angles of deviation.

In order to see if there was any possibility of observing these phenomena, a board was taken and a slot was cut in it to accommodate an acid bottle. This acid bottle was marked on the shoulders in such a way that it was oriented in exactly the same position for each observation. The board was held in retort stands and was tilted in one plane from horizontality through increments of 2½° to a figure of 10°. Water was first used in the bottle, and the position of the meniscus was marked on either side of the slot in the board. The water was then replaced by acid and the same procedure followed before etching had commenced. Between movements of the board a little more acid was added to ensure that the etched lines were not superimposed. The inclination was read in each case by a large protractor and parallel rule.

The following results were obtained for the deviation as recorded by the actual liquid-level line :—

True deviation.	Deviation of surface of liquid.	Average.	Difference.	Remarks.
0·00°	0·25°	—	+0·25°	Water.
0·00	0·25	0·25°	+0·25	Acid.
2·50	2·75	2·75	+0·25	Acid.
5·00	4·50	4·375	−0·50	Water.
5·00	4·25	—	−0·75	Acid.
7·50	7·25	7·25	−0·25	Acid.
10·00	8·75	8·875	−1·25	Water.
10·00	9·00	—	−1·00	Acid.

These results indicate that :—

1. There is no difference between water and acid if the actual fluid level is taken as the basis of measurement.
2. Some distortion of the meniscus must take place at the glass/liquid contact at the higher angles of deviation.

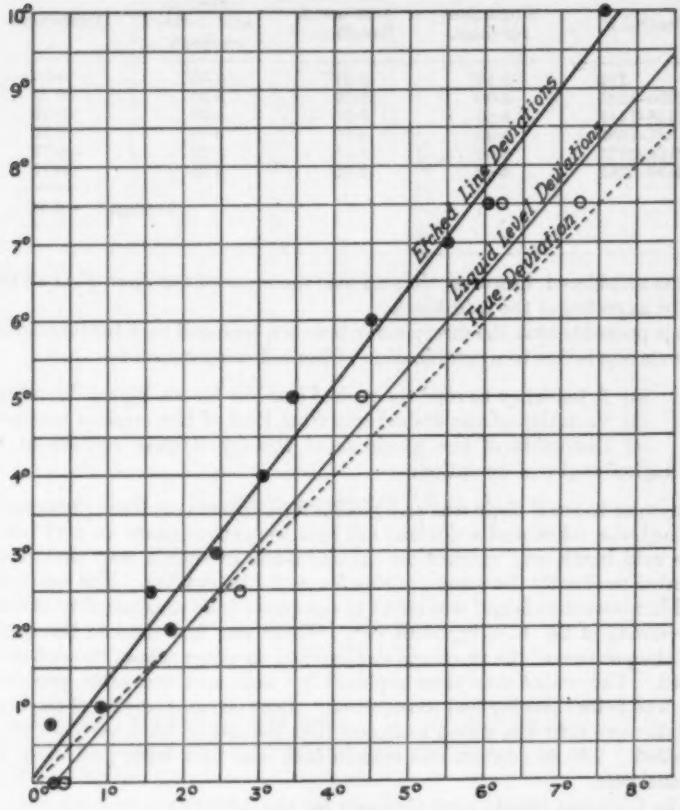


FIG. 2.

CHART SHOWING VARIATION BETWEEN OBSERVED AND TRUE DEVIATIONS. TO CORRECT ACID-BOTTLE READINGS, READ ON HORIZONTAL SCALE AND FOLLOW VERTICALLY TO THICK LINE. THEN OBTAIN TRUE READING ON VERTICAL SCALE.

E.g. Observed Deviation = 2·50°.
True Deviation = 3·25°.

The average of the above readings are plotted on Fig. 2 and the full black line is an average curve through them. It will be noted that whilst the deviation from the true inclination is quite appreciable in the higher ranges, it is of only minor importance in the range usually encountered

in wells intended for verticality. Thus even at a true inclination of 5° the apparent deviation of the liquid level is 4·65°, which is quite sufficiently accurate.

In comparison with the above figures the etched-line readings were as follows :—

True deviation.	Etched-line deviation.	Error.
0·00°	0·375°	+0·375°
2·50	1·56	−0·94
5·00	3·25	−1·75
7·50	6·06	−1·44
10·00	7·56	−2·44

It is at once apparent that the deviation of etched-line readings from liquid-level readings and its much greater deviation from the true readings is a matter of considerable moment.

During the actual process of etching there was an apparent drop in the liquid level which did not appear to parallel the original liquid level. The fall in level is probably due to chemical interaction between the glass and the acid. The apparent non-parallelism of the earlier and later fluid levels may be due to variation of the contact angle between the glass and acid after the liquid and glass have undergone chemical change at the surface boundary.

Conclusions.

If deviations recorded by the acid bottle are merely used as indicators of relative verticality, it is considered that, if they are corrected by the use of the Chart (Fig. 2), they will be of sufficient accuracy for all practical purposes.

The desirability of carrying out oriented surveys in addition to the routine acid-bottle tests is governed by many factors, such as :—

(*a*) The average depth of the wells.
(*b*) The spacing interval.
(*c*) The extent of denudation of the producing formation.
(*d*) The extent of horizontal drift.
(*e*) The lengths to which an operator is prepared to go to ensure penetration of the producing formation at defined geographical points once the underground spacing pattern has been determined.
(*f*) The thickness and persistence of the oilsand bodies.
(*g*) The limits of accuracy in terms of relative verticality that can be obtained by conventional drilling at the average economic drilling speed.

This list could be expanded indefinitely, but the factors cited are sufficient in themselves to indicate the wide scope of the subject.

In the writer's opinion, if corrected acid-bottle deviations are used to calculate horizontal drift, assuming that such deviations are in one constant direction, and if such drift is less than 10 per cent. of the spacing interval, oriented surveys, although desirable, are not essential.

Any consideration of this subject leads inevitably to the conclusion that for all normal drilling operations a high standard of relative verticality should be the aim of all operators. Uncontrolled drilling may result in cheaper drilling costs at the expense of ultimate productivity. This is obviously uneconomical. As a measure of relative verticality the acid bottle is simple and trustworthy in the lower ranges of deviation. In the higher ranges recourse must be had to an oriented survey to determine the point of penetration into the producing zone.

In the three wells cited on page 349 the following horizontal drifts were recorded :—

Well.	Depth, ft.	Horizontal drift, ft.
A	3050	50·0
B	2300	41·5
C	4350	60·0

These wells were not specially selected because of their small deviation and are by no means abnormal.

The average well depth of the completions drilled by Apex (Trinidad) Oilfields, Ltd., in the past year, together with the average deviation and calculated horizontal drift were as follows :—

Average well depth, ft.	No. of readings.	Observed average deviation.	Corrected average deviation.	Average horizontal drift, ft.
4510	1 per 125·6 ft.	0·66°	0·85°	67·0

These figures might be further reduced by the use of longer drill-collar sections.

A short table is appended showing the horizontal drift of a 3000-feet well at various inclinations of the hole from the vertical.

Inclination of hole from vertical.	Horizontal drift, ft.	Vertical depth drilled, ft.
0·50°	26·1	3000
1·00	52·5	2999
2·00	104·7	2999
3·00	156·9	2996
4·00	207·4	2993
5·00	261·6	2989

The author wishes to express his thanks to Messrs. Apex (Trinidad) Oilfields, Ltd., for permission to read this paper.

THE USE OF BITUMEN EMULSION IN SOIL STABILIZATION.*

By A. E. Lawrence, B.Sc., A.I.C.

Introduction.

The subject of soil stabilization is one to which, until comparatively recent years, very little attention has been paid, either in the laboratory or in actual practice. This is even more so when the use of bitumen emulsion as a stabilizing agent is considered.

The development of soil stabilization has led to the establishing of many well-equipped soil-testing laboratories, and to many miles of constructional work being carried out, using the soil as a basis. This is due principally to the investigations of C. A. Hogentogler in America, and other notable soil scientists, such as Terzaghi and Atterburg. Their investigations, however, were not carried out from the point of view stabilization with bitumen emulsion or any other agent initially, but were rather concerned with the design of stable soil mixes by careful control of the grading, etc. This, in turn, led to the addition of various materials to the natural soil in order to improve the inherent stability. Among such materials may be mentioned calcium chloride, sodium chloride, tar, cement, bitumen, etc. The mode of action of these various materials is, however, entirely different. For example, the purpose of adding such chemicals as calcium chloride is to keep the moisture content of the soil at what is termed the " optimum moisture content "—that is, the moisture content at which it exhibits its maximum strength. The action of such binding agents as stable bitumen emulsion differs in that a waterproofing effect is imparted to the soil, and the soil must dry out as far as possible before the maximum resistance to water is attained.

The Use of Bitumen Emulsion in Soil Stabilization.

Definition.

For our purpose, it is convenient to divide soil stabilization into two categories :—

Soil stabilization without waterproofing.
Soil stabilization with waterproofing.

The first group may be defined as " the process of giving natural soils enough abrasive resistance and shear strength to accommodate traffic or loads under prevalent weather conditions without detrimental deformation."

This definition will also apply to the second group, with the proviso that the stabilization be achieved principally by the addition to the soil of a waterproofing agent such as bitumen emulsion.

In the first case stability is imparted to the soil simply by regrading; in the second case this stability is supplemented and made more effective by the addition of a waterproofing agent.

---

* Paper read at a meeting of the Institute of Petroleum Asphaltic Bitumen Group on 16th January, 1940.

Composition of Soil.

In order to obtain a clear idea of what is meant by soil stabilization, it is necessary to consider the composition of soils in general, and the properties of each component part. Each soil may be considered to consist of four groups of materials :—

1. Mineral matter, including colloidal clay.
2. Organic matter.
3. Soil moisture.
4. Soil air.

Of these we are chiefly concerned with the mineral constituents and their relationships with water. It may be mentioned, however, that the presence of organic matter is, in general, detrimental to the stability of the soil.

The mineral matter is composed of particles differing widely in shape, size, and chemical composition, and having vastly different reactions to water. The first essential is to decide on the number of fractions to be distinguished and to define these fractions by particle size. Much confusion has hitherto existed on this point owing to the use of different scales in different countries. The International Society of Soil Science decided to use the following fractions :—

2—0·2 mm. Coarse sand.
0·2—0·02 mm. Fine sand.
0·02—0·002 mm. Silt.
Less than 0·002 mm. Clay.

This scale, however, while very convenient in that the successive particle size limits are at equal logarithmic intervals, is not sufficient for our purpose, and the following classification has therefore been accepted :—

Passing.	Retained.	
1″	¼″	Large stone.
1″	¼″	Medium stone.
¼″	8 mesh (2 mm.)	Small stone.
8 mesh	36 „ (0·42 mm.)	Coarse sand.
36 „	300 „ (0·053 mm.)	Fine sand.
300 „	0·005 mm.	Silt.
0·005 mm.	0·001 mm.	Non-colloidal clay.
0·001 mm.		Colloidal clay.
	(True colloid . . . 0·0001 mm.)	

That portion of the soil passing the 8-mesh sieve is often called the soil mortar, although some workers prefer to reserve this term for that portion passing the 36-mesh sieve.

For general purposes it is customary to classify as clay any material which passes the 200-mesh sieve (0·076 mm.). It is the clay fraction which is the important part of the soil as far as soil stabilization is concerned, and it is worth while considering it in greater detail.

Clay consists of well-weathered materials, chiefly complex silicates, the most important constituent being aluminium silicate. The clay is pre-eminently the active portion of the soil, the coarser fractions being inert. The properties distinguishing clay from the remainder of the soil are :—

1. Retention of water by imbibition. Hence the presence of a considerable

proportion of clay in a soil confers a high water-holding capacity on the soil. This is important in connection with the drainage of a stabilized soil site.

2. Plasticity when mixed with certain proportions of water. No matter how much water is added to sand, a plastic mass is never obtained. When, however, a clay-bearing soil is mixed with a definite quantity of water, defined by the plastic limit, a plastic mass is obtained.

3. The clay fraction confers very marked cohesive properties on the soil. If sand, free from clay, be moistened with water, moulded, and allowed to dry, the sand crumbles with the slightest stress. In fact, the samples cannot be taken out of the moulding apparatus without breaking up completely. When, however, clay is admixed with the sand, a sample is obtained which may be removed from the mould with ease, and which will withstand considerable applied stresses, the force required to break the samples increasing with the increasing clay content. The following figures show the effect of increasing clay content (in this case taken to mean increasing 200-mesh content) as measured by a compression test :

Percentage of Clay.	Compression Test.
0	0 lb.
25	850 lb.
50	1,000 lb.
75	1,250 lb.
100	1,600 lb.

The clay used in these tests was a rather non-colloidal one, otherwise the figures would have been much higher.

Theory of Soil Stabilization.

It is on this cohesive strength of clay that our conception of soil stabilization is based. A clay soil is extremely stable naturally when dry, but when it reaches a definite moisture content, it loses all its stability, and is easily deformed and displaced by a load. A wet clay soil may be considered to have its particles surrounded by two types of water—free and adsorbed. The free water has the ordinary freezing point, boiling point, etc., of ordinary water, and is easily removed by evaporation. The adsorbed water films, however, are held by molecular attraction to the clay particles and have higher boiling points, lower freezing points greater surface tension and are more viscous than free water. Moreover, they cannot be removed by evaporation, and according to Terzaghi, they become semi-solid substances at thicknesses $<$ than 2 millionths of an inch. It is the strength of these thin films of moisture which gives stability to a clay-bearing soil when dry. When a wet clay soil dries, the free water evaporates, leaving the clay particles bound together by the strength of the thin films of water on their surface. This so-called " dry " clay may still contain 5 per cent. of water, which can only be removed by such a temperature as would cause chemical destruction of the clay itself. When, however, this clay is exposed to the action of water, it rapidly takes up water, due to the large number of capillary channels present, and the adsorbed films become thicker, and lose their strength, with the result that the soil mass falls to pieces. The essence of the above theory is due to Terzaghi, who has collected much experimental data in support of it. What happens when a stable bitumen

emulsion is added to the soil is not clear, but the practical result remains that a clay-bearing soil that has been treated with a stable bitumen emulsion in the correct proportion is extremely resistant to capillary water. Sufficient bitumen is not added to waterproof the soil completely, as this would, in most cases, not be an economic proposition. The only case where this is done is in that of a very sandy soil, forming a bituminous sand carpet, which is rather different from soil stabilization proper. In general, enough bitumen is added to ensure that the water absorbed by the treated soil will never be sufficient to render the soil unstable and unable to carry a load.

Classification of Soils.

Before discussing the tests carried out on a soil to determine the amount of bitumen emulsion it is necessary to add, it will be advantageous to consider very briefly the groups into which soils have been classified for engineering purposes. Much of this work has been carried out in America, and was performed primarily to obtain definite figures for a soil which will carry a load under adverse moisture conditions. Such a soil has been termed an *A.1. Group* soil. For re-grading, this is the group that is aimed at. The size analysis of this group is :—

Not more than 50 per cent. to be retained on the 8-mesh sieve. The actual soil mortar to consist of (according to Hogentogler) :

Clay	5–10 per cent.
Silt	10–20 ,,
Fine sand . . .	20–50 ,,
Coarse sand . . .	35–50 ,,

This is stated to be "a well-graded material, highly stable under wheel loads, irrespective of moisture conditions."

There are seven other groups of soil, each of which has some characteristic which renders it unsuitable for bearing a load under moist conditions, unless treated in some way. It is usual to add either sand or gravel, or, in the case of a sand (Group III) clay, to bring the grading within the above limits, when the soil is presumably suitable for carrying a load in the presence of water.

Whilst it is quite true that a soil belonging to Group A.1. will carry a load in the presence of water better than one belonging to any other group, experiment has shown that the statement "irrespective of moisture conditions" needs modification. Samples were prepared of soils of various gradings (Group III omitted), dried, and subjected to a compression test. A curve was obtained which started at 500 lb. for the A.1. soil (with the lowest amount of clay) and rose to 2600 lb. for a soil containing the highest amount of clay (the soil actually belonged to Group VII). When these samples were subjected to a capillary water-absorption test, followed immediately by a compression test, the results were reversed, the A.1. soil taking a load of 20 lb., but the rest collapsed under their own weight.

Thus, although the A.1. soil withstood the action of water better than the remainder, the bearing capacity would not appear to be sufficient under *any* moisture conditions. In any case, the working limits are very restricted.

When, however, a well-graded soil is either completely or partly waterproofed with a stable bitumen emulsion, it is enabled to carry a load in the presence of water.

By complete waterproofing is meant imparting to the soil ability to resist complete immersion in water. This can only be achieved economically in a few cases.

By "partial waterproofing" is meant rendering the soil sufficiently resistant to *capillary* water absorption to enable it to carry a load under wet subsoil conditions. This may be economically achieved by the addition of bitumen emulsion to the soil.

Tests.

Turning now to the tests carried out on a soil which it is proposed to stabilize with bitumen emulsion, it is obvious that the most important is the *size analysis* test. For this purpose the soil is carefully sieved through the 1-inch, ¼-inch, 8-, 36-, and 200-mesh sieves. It is washed through the 200-mesh sieve until the issuing water is clean.

For determination of the percentage passing 0·005 mm. and 0·001 mm., a method dependent on the rate of settling of deflocculated soil is used.

It is advantageous to plot a grading graph, the percentages of each size being plotted on an arithmetic scale and the actual particle size on a logarithmic scale.

Having obtained the size analysis of the soil, it is usual to determine the liquid and plastic limit of the soil. The *liquid limit* may be defined as that percentage of water which it is necessary to add to oven-dried soil in order that the mixture may flow freely. It is determined by a standard method using a special grooving tool.

The importance of the liquid limit from the point of view of stabilization with bitumen emulsion lies in the fact that it is only when the soil is in this condition that it may be mixed evenly and easily with the emulsion to give a perfect dispersion of the latter throughout the soil mass. In applying this statement to practice, however, due consideration must be given to climate and other factors, such as drainage, appertaining to the area in question.

The *plastic limit* is defined as the lowest moisture content expressed as a percentage of the oven-dried soil at which the soil may be rolled into threads ⅛-inch in diameter without the threads breaking into pieces. Here again it is very simply determined by a standard method.

It should be noted that both the liquid and plastic limit tests are carried out on that portion of the soil which passes the 36-mesh sieve.

The plastic limit of a soil represents that moisture content at which optimum consolidation will take place. Once the soil dries beyond the plastic limit, consolidation becomes more difficult, due to the tendency of the soil to crumble under the roller.

The difference between the liquid and plastic limits of the soil is known as the *plasticity index* of the soil. This index is a measure of the range over which the soil will remain plastic.

It is possible to calculate the plasticity index approximately from the liquid limit of the soil, if the type of soil is known. Generally speaking, the finer the state of subdivision of the soil, the higher is the plasticity index.

Having carried out a size analysis and determined the liquid and plastic limits of the soil, it may then be assigned to one of the eight groups. This then gives an excellent indication of the probable behaviour of the untreated soil under varying conditions. When, however, it is proposed to treat the soil with bitumen emulsion, these groups are relatively unimportant, as stabilization by this method permits of a much wider variation in the grading of the soil than any other method. It has, in fact, been stated by Hogentogler himself in a review of the study of Road Subsoils, reported in *Public Roads*, Vol. 19, No. 6, that "where only fine or poorly graded materials are available, asphaltic binders may be utilized to provide stable base courses to be covered with bituminous surfaces."

In practice, the limit for the quantity of fine material is set chiefly by economic considerations. Where too high a percentage of 200-mesh material is present, the quantity of emulsion involved makes the process too expensive. It appears from specifications issued by various American Highways Authorities, such as the Bureau of Public Roads, Texas State Highways, Ohio State Highways, etc., that it is not desirable for the percentage passing the 200-mesh sieve to be greatly in excess of 25. This has been precisely our experience both in the laboratory and in practice, that the best results are obtained, from both the technical and economic standpoints, when the 200-mesh content is between 20 and 30 per cent.

It is not claimed, however, that a satisfactory base cannot be obtained with low 200-mesh contents, but such cases cannot be termed true soil stabilization, which relies on the bonding action of the clay for its strength, as here the bitumen/clay ratio is such that the strength results from the bitumen itself. In order to determine whether satisfactory stabilization may be achieved with bitumen emulsion, cylinders are made and tested for capillary water absorption by standing them on a wet base for a definite time.

It may be wondered why the samples are not tested for water absorption simply by immersing them in a dish of water. The answer to this is two-fold :—

In the first place, our conception of soil stabilizaton does not mean the complete waterproofing of the soil. What is inferred by soil stabilization with bitumen emulsion is rendering the soil sufficiently resistant to capillary water absorption to enable it to carry a load when laid on a wet foundation.

In the second place, total immersion would not represent the conditions obtaining in practice, where it would not be considered good engineering to have the subgrade of a road, parade ground, etc., continually under water. The top of a stabilized soil base is always sealed with a strongly water-resistant armour coat. Thus, the only source of water for the stabilized soil is from the subgrade, from which it will only take up water by capillarity.

These conditions have been reproduced as far as possible in the absorption chamber, the source of water being at the bottom only.

The second test carried out on these samples is the *compression test*. The samples immediately after removal from the water-absorption test are compressed and the maximum reading on the gauge before the sample cracks is noted. The test is carried out under standardized conditions, and pressure is applied at a uniform rate. It has been found that an untreated

soil, when tested in the above manner, will not stand much more than 15 lb. per square inch, whereas the minimum pressure for a properly stabilized sample is in the region of 100 lb. per square inch. It is, in fact, not unusual to obtain a soil which, when properly stabilized, and after exposure to the water-absorption test, will withstand a pressure of 250 lb. per square inch.

The tests outlined above afford an excellent indication as to whether satisfactory stabilization has been achieved with bitumen emulsion. For confirmatory purposes, however, further detailed tests are carried out, which it is not possible to describe in a paper of this type.

The normal quantity of emulsion required is 6–10 per cent. of emulsion by weight of the soil fraction, exclusive of stone. This might appear to be rather a low percentage, but practical results have justified its use. If I may again be allowed to quote from the previously mentioned article by Hogentogler in *Public Roads*, he states :—

"In the case of bituminous treatments, there is apparently a rather flexible range of quantity of treating agents which may be used. As judged by their behaviour, mixtures near the upper limit of the range mentioned appear to be more critical than those near the lower limits, no radical failure being noticed in sections approaching excessive leanness, whereas an excess of bitumen has immediately produced plasticity and loss of stability."

Practical Work.

The method adopted for the execution of soil stabilization in practice depends to a very large extent on the area in question. Where a relatively small area, such as a footpath or a small school-yard, is to be treated, it will probably be most convenient to mix the soil by hand or in a concrete mixer. For a larger area—say, over 5000 square yards—it is usually more convenient to carry out the work using earth-moving and mixing machines drawn by caterpillar tractors.

When the rapid treatment of a large area is required, a special mixing machine is used.

It is not proposed to describe these methods in detail, as they are best observed from the films.

Conclusion.

Whilst it has not been possible in the time available to deal with the soil stabilization in all its aspects, or to elaborate on such questions as laboratory technique and control methods, it is hoped that sufficient has been said to indicate what are believed to be the underlying principles. Much interest has been shown in the subject in the last few years, and this interest shows no signs of waning. It is in America, however, that the greater part of the work has been carried out. In that country official tests have been carried out using different materials for the treatment of soils—*e.g.*, bitumen emulsion, tar, cement, etc.—and I cannot do better than conclude by quoting some of the conclusions that have been reached by the American Bureau of Public Roads as reported in various issues of their journal, *Public Roads*.

1. "It is indicated that all the methods employed may be successful, but the relative economy of the various methods depends on local conditions associated with the project. Mechanical stabilization assumes the availability of an ample aggregate supply. Economy limits cement stabilization to soil types requiring a relatively small amount of cement. In other cases, bituminous treatments will generally prove more economical and adaptable."

2. "In bituminous stabilization three methods of treatment—machine mixing, sub-oiling, and road mixing—have all been successfully employed. The sections of road-mixed material are of too recent date to be fairly compared with the other sections, but the results obtained so far give no indications of inferiority."

3. "Under the conditions used, and based on the length of service thus far observed, no appreciable difference has been noted in the stability produced, or the durability obtained with the various bituminous agents used."

SOIL MECHANICS IN FOUNDATION ENGINEERING.*

By R. L. JAMES, B.Sc., A.M.Inst.C.E., A.M.I.Struct.E.

FOR many years engineers and chemists have studied the properties of building materials such as steel, concrete, and timber, until to-day it is possible to design huge chords of a Sydney Harbour Bridge in high-tensile steel alloys and to compute the effects on it of the primary stresses of loading, impact, and wind, and the secondary stresses imposed by temperature and joint deformation. Our knowledge of concrete water cement ratios, grading, and workability also permits the safe design of a boulder dam, or a fifteen-storey reinforced-concrete building subjected to earthquake stresses.

It is only during comparatively recent years, however, that soil has received much attention as an engineering material. This despite the fact that soil problems are important in earth-fill dams, stopbanks, retaining walls, building and bridge foundations, irrigation and drainage schemes, tunnel linings, railway cuttings and embankments, harbour reclamation, landing-fields and road subgrades.

Agricultural soil physicists such as Atterberg, Oden, Robinson, and Russell were among the first to establish definite soil tests as a means to describing soils of which there was some practical field experience. Two English engineers, Crosthwaite and Bell, published papers on the lateral pressure of soils on retaining walls, in the *Proceedings of the Institution of Civil Engineers.*

Then came Dr. Terzaghi, who has exerted a very considerable influence over the subject from an engineering point of view. As lecturer in the American Roberts College in Constantinople, as Professor of Soil Mechanics at Massachusetts Institute of Technology, and as Professor of Civil Engineering at the Hoch Schule, Vienna, he has concentrated on showing what movements of water will occur in the soil under given forces of load or water pressure, and what settlements or slips may result. Dr. Casagrande of Harvard University has elaborated on the calculations of Boussinesq in order to predict the stresses imposed at different points of a soil mass under large area foundations of different shapes. The Americans Gilboy, Bouyoucos, Krynine, Hogentogler, and Proctor have devised or modified tests as an aid to describing the soils encountered. Men at the Rothamsted Agricultural Experimental Station, such as Russell, Coutts, Keene, and Rachowski, have thoroughly explored several other tests, particularly those dealing with water absorption and swelling. Dr. Hanna and Dr. Tschebotareef have done valuable work in Cairo comparing laboratory predictions of settlement with levels taken periodically on actual buildings. The American Bureau of Roads has divided soils into eight classes for highway work, and this classification has been copied with

---

* Paper read at a meeting of the Institute of Petroleum Asphaltic Bitumen Group on 16th January, 1940.

little change by the Main Roads Board of Victoria, Australia. Soil laboratories have been organized more recently in England in collaboration with the work of the Building Research Station and the Road Research Station.

Soil work was commenced in New Zealand at Canterbury College in 1930. About the first four years were devoted to a study of the tests, and the remainder of the time to building up tables of soil information, tracing relationships between the various physical properties, and advising on actual practical problems of construction and design. As a result we have now been able to select a few tests on which the greatest number of physical properties of engineering importance depend. We use these tests to compare new soils with those of which we have definite constructional experience.

There is an increasing flood of literature on soil mechanics these days in the technical press—some printed in German, others in Dutch, Swedish, Russian, and in Calculus. Articles on soil mechanics by mathematicians with no engineering experience and by engineers with shaky laboratory technique must often be read with a certain amount of discrimination.

Soil Behaviour.

Soils consist of sand, silt, clay, and humus or organic matter. The sand may be silica, and the clay hydrated aluminium silicate, but the names do not depend on chemical composition. Clays owe their behaviour chiefly to the fact that the grains are very small and platy rather than spheroidal. The humus is important chiefly because of its effect on the water-holding capacity of the soil. The fine particles of clay will remain suspended for a long time in water—that is to say, they are colloidal. They have a surface area large compared with their weight, and hence the electrical charges on their surfaces are much more important than the forces of gravity. Small particles of clay may be introduced into a drop of water on the slide of a high-powered microscope, and it will be seen that many of the particles or specks are constantly in motion, darting this way and that—in Brownian movement—due to bumps by molecules of water always in vibration.

It is considered that each colloidal speck is surrounded by a film of liquid which helps to cushion the blow when two particles collide. This film may be charged negatively or positively, and if the charges are altered by adding an electrolyte or by passing a current through the column, the protecting film leaves the particle. On collision they stick together (or "flocculate"), their weight becomes more important than their surface charges, and they sink. This flocculation—or gathering together in flocks—is well known, whence the use of lime to improve the tilth of the soil in agriculture.

Influence of Grain Shape.

There is the famous Reynold's bag experiment. A rubber bag was filled with sand and the stopper opening sealed; the shape of the bag could be easily altered. The voids were then filled with water and the top was sealed. The bag became as solid as a rock. When clay was tried the bag could be deformed due to the sliding of some particles over others. This

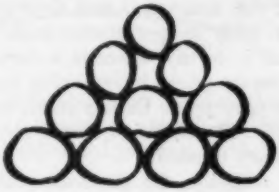
occurred because the clay grains were platy. This platyness makes the determination of the settling rate of clay particles in suspension rather an arbitrary measurement for the grains with the same horizontal diameter fall at the same rate—like tin plates in a dividing competition. We pretend that we are measuring the diameters of spheres.

A very fine or colloidal powder or quartz has no plasticity because the grains are not platy.

Influence of Grain Size.

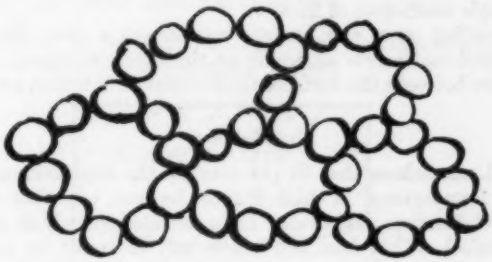
Why does a clay soil hold a lot of water? Much more than sand.

In a suspension column sand grains, under the influence of their weight, roll until they come to depressions and build up a cannon ball structure.



With this formation equal spheres would have a maximum volume of voids of 47·6 per cent.

But if the falling particles are very small, the initial friction will check their rolling tendency so that they stick and build up a fairly spongy structure. If colloidal particles are gathered in flocks by means of an electrolyte, the clay forming may have an open texture with 94 per cent. voids.



More water can therefore be retained.

Capillary Forces.

Surface tension at the top of a fine capillary tube will lift water up a considerable height. This tension force or negative hydrostatic pressure has its maximum amount just under the surface of the column. It can be understood that this effect becomes a big factor when there are thousands of these capillaries to a square inch of clay. Of course in a soil the voids do not form straight tubes. The voids are very small too, so that the ordinary laws of capillarity and viscosity may not perhaps apply rigorously.

In some experiments it was found that for clay with a compressive strength of 740 lb. per square inch, the maximum capillary force = 2440 lb. per square inch; clay with a compressive strength of 1220 lb. per square inch, the maximum capillary force = 4840 lb. per square inch. In loading tests there is a difference between the downward vertical load applied and the upward capillary force. The unbalanced pressure forces the water out of the test specimen. Since that volume of water has gone, the particles can move together. In other words, settlement occurs. Since it takes time for the water to go out, settlement may occur slowly.

Shrinkage.

The shrinkage on drying is stated to be caused by the surface tension existing in the voids of the moist soil and drawing the particles closer. The force may be up to 5000 lb. per square inch, and acts towards the centre of the clay. That is to say, there is a very considerable suction; whence the use of clay beauty-packs in removing impurities from the skin. Since the clay has more pore space than a sand, there is more shrinkage in a clay than in a sand. The cohesion across any section of a clay soil is due to this same capillary tension.

Dried soils still show cohesion, for the reason that they contain some water which cannot be evaporated.

Swelling.

If the soil be covered with water, the surface-tension forces vanish and the specimen swells.

Friction.

There are several different types of slips possible in sand, and there is no definite single coefficient of friction.

A weight resting on a clay surface compresses a clay, the outflowing liquid is trapped and exerts an uplift on the external object. With such a small pressure between the surfaces the friction force is low, and the object slips.

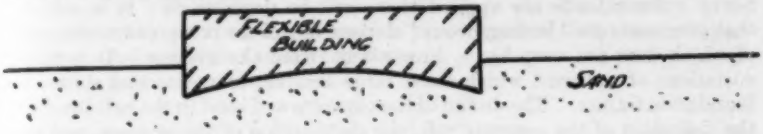
Foundations.

I have read somewhere that 70 per cent. of the engineering failures are due to faulty foundations. I think it must be true, too, that many buildings which are standing well to-day have foundations which are over-safe and uneconomical. This does not reflect any discredit on the engineers who have pinned their faith to a 12-inch block of hardwood loading test, or who have relied on the driving of test-piles. It is just that the whole matter is very complex, and as time goes on we are learning a little more about the many factors involved. It is not yet possible to give a completely connected story or to lay down hard-and-fast rules for the guidance of all engineers, but it is possible to get a little closer than before—perhaps the factor of safety can be decreased from say $2\frac{1}{2}$ to $1\frac{3}{4}$ in a great many cases.

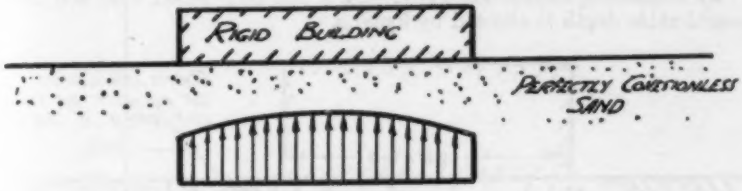
It is not correct to imagine that because 2 tons can be carried on 1 square foot, it is only necessary to make a rigid footing slab 100 square feet in area to carry 200 tons. There are too many other factors for us to do that any longer.

1. *The Distribution of Stresses below a Foundation.*

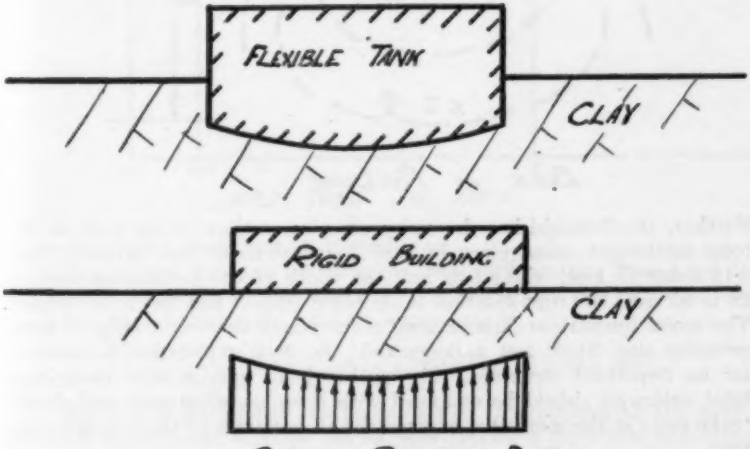
Dr. Terzaghi, of Vienna, assisted by the American Foundation Committee of the American Society of Civil Engineers, has organized a survey of the settlement of a large number of European buildings and structures. In each building he has fixed about twenty brass tubes, into which reference-plugs screw, and these are observed at intervals with a water-level fitted with a special micrometer. A great deal of interesting information has been collected in this way, and in particular he has found that a building on shallow foundations sinks around the edges.



This was particularly noticeable with flexible tanks. If the building is quite rigid, and cannot sink more at one place than another, then the soil reactions are least at the sides and greatest in the centre.



(I should mention in passing that clays are the opposite—*e.g.*, flexible tank behaves as shown in the diagram below.)

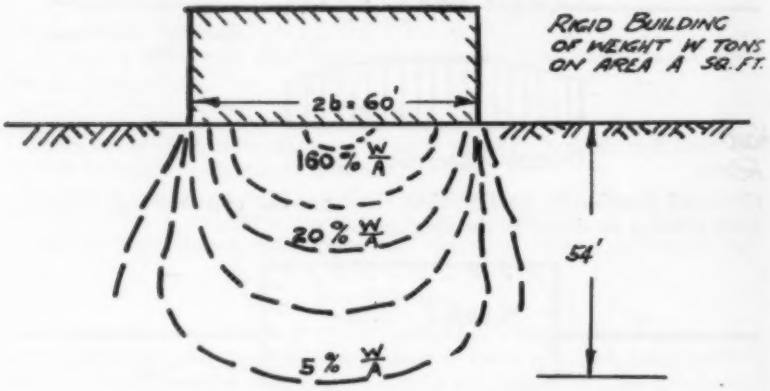


If foundations are placed deeply in sand, they tend to behave as clays in this matter of pressure distribution, but there is some doubt on this point. It will be found easy to remember that for a flexible structure

"*Surface sands settle at the sides.*"

The curved surface that would be produced if the superimposed structure were perfectly flexible and the soil were perfectly uniform is called "the basic form of the settlement trough." Of course this is seldom completely realized in practice. Where hard spots of soil occur there will be local "pimples" on the "basic trough." Where there are soft spots or where heavy column loads are applied there will be depressions. It is seldom that one meets an "homogeneous" deposit of soil the compressive strength of which does not vary by $\pm$ 50 per cent. from the average. It is these variations of upthrust which cause large bending moments and shears in foundation frames. The design of the concrete and steel in the raft involves the deflection of the concrete raft, the distribution of the stresses, and the variability of the soil settlement. Articles on the design of rafts in this way appear in *Concrete and Constructional Engineering*, 1936 (giving a very heavy design) and in the *Structural Engineer*, March 1935.

By Boussinesq's mathematical studies it has been shown that soil at a considerable depth is affected by loading.



BULB OF PRESSURE.

Further, Dr. Terzaghi has shown by experiment that 75 per cent. of the total settlement takes place in *sand* foundations in the territory from $0{\cdot}1b$ down to $1{\cdot}8b$, where b is half the width of the foundation—*e.g.*, if $2b$ is 60 feet, the consolidation takes place from 3 feet down to 54 feet. The worst foundation failures may occur where there is a strip of compressible clay 50–80 feet underground. So deep exploration is essential for an important structure. The author is of opinion that each large local authority should be equipped with deep sampling gear and should make tests at the municipal expense for all buildings of three storeys and over.

2. *Ratio of Stress to Settlement.*

The majority of soil engineers use a method adopted by Dr. Terzaghi.

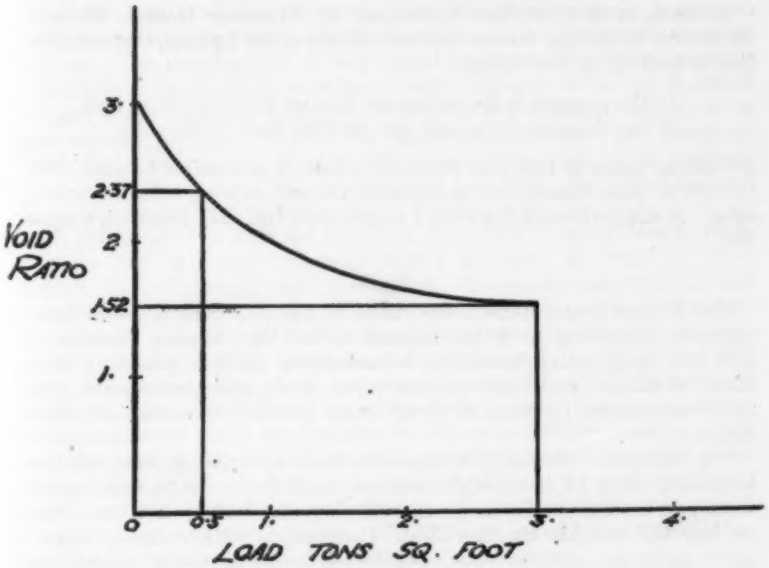
A soil pat (undisturbed), obtained with a special sampling device, rests between two porous stones and is compressed by a piston fitted with accurate dials to record the amount of movement. There must be a free outlet for water squeezed out of the pore spaces.

Moisture content, compression settlement, and voids ratio are all closely connected, and one of these is plotted against the pressure in tons per square foot or kgm./cm.^{2} The voids ratio $= \frac{\text{vol. of voids in soil}}{\text{vol. of solids in soil}}$. This is given the value e_1 when the pressure is p_1, or e_2 when the pressure is p_2.

Then total settlement under foundation

$$Q = D_1 \times \frac{e_1 - e_2}{1 + e_1}$$

Where D_1 = thickness of soil layer under pressure p_1.



For example in a case given by Hogentogler.

e changes from 2·37 to 1·52 when the total load changes from $\frac{1}{2}$ ton to 3 tons per square foot. So that if 3 tons per square foot rests on this muck soil (5 feet thick), the total settlement will be

$$Q = \frac{2{\cdot}37 - 1{\cdot}52}{1 + 2{\cdot}37} \times 5 \text{ feet} = 1{\cdot}26 \text{ feet} = 15 \text{ inches (say)}.$$

3. The rate of settlement can be calculated from measuring the speed at which water passes through the soil and making a correction according

to the ratio of thickness of soil layer in the field to thickness of soil sample in the laboratory.

Professor Buisman finds that when compression settlements are plotted against the logarithm of the time in minutes, a straight line is obtained. He then very bravely predicts how much a building will settle in ten centuries.

A variation of the general method of calculation is used by the Foundation Soils Research Laboratory in Cairo.

They find Young's Modulus for the soil by loading it in an oedometer. Then the actual Young's modulus in the field is taken to be from 1¼ to 4 times this, according to the class of soil. Then for a given stress the strain can be calculated. The stress is the weight of the building per square foot of foundation at a given depth, and the strain is the settlement divided by the thickness of the oil stratum.

Fourteen buildings are under observation for settlement in Cairo—this in spite of some reluctance by engineers, architects, and builders, who maintained that their buildings were so well designed and constructed as to be free from the least settlement.

Another method is that formulated by Professor Housel, Michigan. He shows, by loading various sizes and shapes of steel plates, that a foundation is held up by two things :—

(1) the pressure in lb. per square foot on its flat surface, and
(2) the shearing force and skin friction force on its sides.

By taking three of four size foundation tests it is possible to affix values to each of these effects, and so calculate the safe bearing value for a larger area. A soil may carry 1 ton on 1 square foot, but only 3 tons on 6 square feet.

Roads.

The United States Bureau of Public Roads has done a great deal of valuable pioneering work in subgrade soils. The Bureau classifies the soils into eight groups, according to mechanical analysis, plasticity limits, lineal shrinkage, and moisture equivalent tests, and prescribes a treatment and design for each of those types of soil. One example should suffice.

For example, "Group A-5 subgrades have a shrinkage limit likely to be greater than 30 and a high moisture equivalent. Exceptions occur—the liquid limit is usually larger than 35, but may be less than 25. Roads on this soil provide elastic riding. Compaction with a heavy roller is apt to cause non-uniform rebound of the soil during pavement construction. Drainage must be provided to intercept seepage and reduce the adverse effects of frost heave. In the treatment a bituminous application should be followed by a cushion and a porous base course. Clay may be added with good results. Macadam should not be used until the subgrade has been stabilized by both treatment and drainage."

There is still a certain vagueness in the classification. It is full of such terms as "may be," "usually," "likely to be," and in practice it will be found that the test values for a soil "usually" permit it being placed in two or even three groups out of the eight. The author feels that this is

because several of the tests chosen measure properties only rather indirectly connected with road construction practice. You can take just that portion of the soil which passes the 40-mesh sieve and find what moisture content it will have when you can roll it in a thread the size of a match—that is, find the lower plastic limit. Or you can find how many times you must knock a dish in a certain way to make a crack in the soil heal up along 1 mm. of height—that is, find the Lower Liquid Limit. You are measuring something about a portion only of the soil under forces and conditions with no proved theoretical or practical relationship to ordinary road engineering. The other two tests employed—centrifuge moisture equivalent and shrinkage limit—although presenting some laboratory difficulties, have a more definite connection with practice, but the Bureau classification tests make no attempt at finding the properties most important to the road engineer—the strength of the soil in tension, compression, or shear. The author does not suggest that the Atterberg plasticity tests be discarded, only that they should be supplemented for classification purposes.

Road subgrade design has been important in New Zealand, because thousands of miles of the county roads and highways run through districts which cannot as yet afford to provide bituminous, tar, or concrete wearing-surfaces. The development of fast motor traffic has therefore created a demand for a strong stone macadam or metalled road, as we call it, which will not crush, ravel, or corrugate, in wet or dry weather, under 100 or 1000 vehicles per day. Briefly, the early practice was to use spawls of stone from 3 to 6 inches, blinded with quarry stone from $1\frac{1}{2}$ to $\frac{1}{2}$ inches. By about 1915 all stone had to pass a $2\frac{1}{2}$-inch ring. In 1920 advanced county engineers were ordering 2-inch to dust metal and putting in an 8-inch thickness. In 1928 the engineers demanded so many tons of $1\frac{1}{2}$–$\frac{3}{4}$, so many $\frac{3}{4}$–$\frac{1}{2}$, $\frac{1}{2}$–$\frac{1}{4}$, and so many tons $\frac{1}{4}$ to dust. In 1936 the New Zealand Main Highways Board advised for important roads that the soil mortar material passing shall we say 10 mesh, must have a tensile strength of at least 15 lb. per square inch, a lineal shrinkage of less than 5 per cent., and must have at least 25 per cent. passing 200 mesh. Corrugations will form wherever the subgrade is low in tensile strength, and frost heave or swelling will occur if the lineal shrinkage is too great. Bases of concrete, bituminous, or tar roads are designed on the same principle, and in many cases it is considered sufficient to use a 4-inch thickness of graded stone and sand-clay in order to carry a $1\frac{1}{2}$-inch wearing coat for secondary main highways. The stone, sand, and clay are watered and thoroughly mixed on the road by auto patrol graders. Traffic may be used for consolidation when the clay content is sufficiently high.

A further development of road subgrade design is the use of bituminously stabilized soil in this country, where the high compressive strength of a dried sand clay is maintained by bituminous emulsion waterproofing. Since the natural materials are used in situ there is little cost for excavation and little cost in the haulage of materials to the site. Speed of construction is of the order of an acre and a half per day. There are a large number of practical points to be watched in the design and construction of stabilized soil roads, car parks, and aerodromes, points such as the choice of aggregates, design and control of mixes, surveying, drainage, choice of plant,

organization of labour, and the variation of the process under changing weather conditions. It is not possible to include these in the short space of this paper.

In general, progress in soil mechanics can be achieved only by a close co-ordination of accurate laboratory work and vigorous civil engineering work in the field. In addition, there must always be intermediate tests—large-scale laboratory specimens and small field experiments to make a continuous connection between the laboratory and the job. Only in this way can we hope to avoid the errors which lie in wait for a pure theorist or a science despising foreman.

The author has attempted only a very general and rather elementary outline of the present position in regard to soil mechanics, and hopes it will be agreed that there is some interest and importance in even a very commonplace material.

DISCUSSION.

MR. A. H. D. MARKWICK (*Road Research Laboratory*) said: Mr. James has criticized the "simplified" tests for soils on the ground that they do not measure any true physical property of the soil which has a direct practical application. They cannot, of course, give any direct measure of the mechanical properties of the soil, for these depend on the original granular structure, which is destroyed in making the tests. The tests are therefore identification tests, and the test values obtained have been shown to be closely related to the mechanical analysis of the soil. In spite of the obvious grounds for criticism, the tests have been widely accepted. They were adopted as "Tentative Standards" by the A.S.T.M. in 1935, and I understand that last year they were accepted as "Standards."

The effective stabilization of soil depends on the control of the moisture content. Providing the moisture content is kept below certain limits depending on the type of soil, the soil will remain hard indefinitely. The soil must not, however, dry out too much, or the surface will disintegrate under traffic. Stabilization with bitumen emulsion is only one of many methods which have been tried in recent years, and the voluminous literature on the subject recorded, for example, in "Road Abstracts" affords abundant evidence of the efforts made abroad in recent years to develop this type of secondary road construction. So far as this country is concerned those methods of stabilized soil construction which rely on the drying out of the mixed material are restricted to the spring and summer months, and I think it is important if soil stabilization in this country is to develop along sound lines that such limitations should be carefully borne in mind. One speaker has referred to the importance of sealing the surface of soil roads, and I should like to support him on this point. In fact I was told last year that it had been possible in the Baltic countries to construct aerodromes by merely applying surface dressings using bitumen emulsion. This was applied in the summer. I have not, however, heard how far this type of construction was really durable and to what extent it is resistant to the severe frost action experienced there every year. I should like in conclusion to congratulate both the authors on the lucid presentation of their papers.

OBITUARY.

DR. CHARLES K. FRANCIS.

DR. CHARLES K. FRANCIS died at his home in Tulsa, Okla., on 25th March, 1940. He was well known as the technical editor of the *Oil and Gas Journal* from 1926 until the time of his death.

Dr. Francis was born in Chester, Pa., on 17th June, 1875, and graduated from Brown University, Providence, R.I., in 1899. He then served as an instructor at Brown, and was later a member of the faculty of the Georgia School of Technology. In 1904 he obtained his master's degree at Brown, after which he taught chemistry in Converse College, South Carolina, the University of Illinois, and the University of Missouri. In the last-named institution he received the degree of Doctor of Philosophy in 1910, moving then to Stillwater, Okla., where he was Professor of Petroleum Technology in Oklahoma A. & M. College, and also chemist at the Agricultural Experiment Station. He remained in Stillwater until 1917, when he moved to Tulsa to enter the practical work of the oil refinery.

Dr. Francis served successively as chief chemist for Cosden & Co. (now Mid-Continent Petroleum Corp.), manager of refineries, and chemical director for Transcontinental Oil Co., chief chemist and technical superintendent for Cosden & Co., vice-president in charge of manufacturing for Producers & Refiners Corp., and chief technologist for Skelly Oil Co.

From 1920 to 1924 he was a member of the advisory committee of the Federal Specifications Board. In 1925 he served as President of the Oklahoma section of the American Chemical Society, as a councillor in 1926, and was for three years state chairman of essay contests in the organization.

Dr. Francis was elected a Member of the Institute of Petroleum in 1927, and was a delegate to the World Petroleum Congress in Paris in 1937, serving as Honorary Chairman in the section of physics, chemistry, and refining.

GEORGE WILLIAM EDWARD GIBSON.

GEORGE WILLIAM EDWARD GIBSON died in September 1939, at the age of 62. He was born in Rotterdam, and at the age of 16 entered the Rotterdam house of Messrs. Tangye of Birmingham. In 1905 he took over the representation of Messrs. Hayward–Tyler & Co., Ltd., in North-western Europe, residing at The Hague. During the war of 1914–1918 Mr. Gibson worked on the military and naval intelligence staff of the British Government in Holland. In 1919 he was transferred to the London office of Messrs. Hayward–Tyler & Co., Ltd., with whom he was associated until his death.

He was a Member of the Royal Institution of Engineers of the Netherlands, and was elected a Member of the Institute of Petroleum in 1920. Mr. Gibson enjoyed the friendship of many engineers both in this country and on the Continent, and was an expert in the problems of pumping petroleum and its products.

ROBERT JOSEPH STRINGER.

Robert Joseph Stringer, A.M.I.Mech.E., who died on 25th January, 1940, was connected with the oil industry for over thirty years. He was born in 1881, and was educated at Halifax. He was apprenticed with Messrs. Cole, Marchent, and Morley, Ltd., of Bradford, from 1896 to 1901, and at the same time he attended evening classes under Professor Charnock at the Municipal Technical College. On completing his training he joined the staff of Messrs. Edward Ripley & Son, Ltd., of Bradford, as a draughtsman, and after leaving the company in 1903 he held similar positions with a number of firms, including Messrs. Dick, Kerr and Co., Ltd., of Preston and Messrs. Davey, Paxman and Co., Ltd., of Colchester.

He became technical and consultant engineer to the Vacuum Oil Co., Ltd., in 1906, and during the next twelve years he travelled to Australia, New Zealand, and New York in the firm's interests. From 1918 to 1920 he practised as a consulting oil engineer in America and Europe. He was then appointed managing director and lubricating oil expert of the Record Oil and Grease Co., Ltd., a position which he held until his death.

Mr. Stringer was elected a Member of the Institute in 1921.

FRANK BENJAMIN LEA.

Frank Benjamin Lea died on the 21st April, 1940, at his home in South Australia. He was eighty years old. Mr. Lea was born in Leicestershire and educated at Owens College, Manchester, and London University, where he graduated in 1882. For over twenty-five years he was engaged in electrical and mechanical engineering work in England. In 1910 he went out to Rumania as Joint Manager of the Rumanian Oilfields, Ltd., at Ploesti. He returned in 1914 to the London offices of the Anglo-Mexican Petroleum Co. For twelve years he was in charge of their foreign business in crude oil and fuel oil. In 1926, at the age of sixty-seven, he went out to Australia to become Secretary and Manager of a company marketing asphalt products in South Australia—Messrs. Asphalt Cold Mix (Aust.) Pty., Ltd., Melbourne. He continued his association with this company until the time of his death.

Mr. Lea was elected an Associate Member of the Institute of Petroleum in 1919. He was transferred to Member in 1927, and to Fellow in 1938.

Although he was nearly eighty years old at the time of his election to Fellowship, Mr. Lea had written to the Council expressing his appreciation of this honour, and relating how he valued his monthly journals.